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SIMULTANEOUS PRODUCTION OF ENERGY AND SPECIALTY PRODUCTS FROM LOW REACTIVITY COAL

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FINAL REPORT

SIMULTANEOUS PRODUCTION OF ENERGY AND SPECIALTY PRODUCTS FROM LOW REACTIVITY COAL

By

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1.0 SUMMARY

This report details a study of the Production of Energy and Specialty Products for Low Reactivity Coals carried out in 1991 and 1992. It was designed to establish the technical and economic viability to produce activated carbon from anthracite. Previous work at the bench scale had shown promising results using a fixed bed treatment. A pilot plant was constructed and operated in a fluidized bed mode and the earlier fixed bed results confirmed.

Activated carbons were produced from Mount Klappan anthracite with surface areas up to 1240 m^2/g which is higher than the commercial products available. Characterization of the Mount Klappan anthracites show comparable performance to commercial products for small and large organic molecules, but a reduced capability for polar, ionic or molecules of complex structure. The Mount Klappan product showed superior sorption rates for gold recovery but with reduced capacity.

Discounted cash flows (DCF's) were calculated for a combined activated carbon and electric power plant which produced 101,000 tonnes/yr of activated carbon and 165 MW of electric power with power delivered at 3.5¢/kWh. Two cases were investigated: one assumed an activated carbon price of $1,000/tonne, the other $1,500/tonne. The results of the DCF calculations show an (after tax) internal rate of return of 15.2% for the $1,000/tonne case and 25.0% for the $1,500/tonne case. These economics were very positive considering previous studies have shown an average activated carbon price of $1,900/tonne in the market place.

Before commercialization a larger scale pilot plant will be needed. To further refine the technology assessment some further small scale technical studies are also recommended. These include: the detailed characterization of the water and solid waste streams to verify disposal options; assessment of modified activation techniques to enhance product performance; assessment of other low ash, low volatile, non-swelling coals.

2.0 INTRODUCTION

This report describes work performed during 1991 and 1992 on DSS Contract 06SQ-23440-0-9014, "Production of Energy and Specialty Products from Low Reactivity Coals".

The study was carried out to establish the technical and economic viability to produce activated carbons from anthracite. Previous work had shown that at the laboratory bench scale, activated carbon with very high surface areas could be obtained in a one step process. The gas produced simultaneously was suitable for power generation. In this current work a fluidized bed pilot plant was constructed and operated to produce kilogram sized samples. This allowed for detailed sample testing in end-use applications of the carbons. It also provided data for an economic evaluation of the process concept.

Gasification of high rank coals generally requires longer residence time and higher temperature because of their low reactivity. Production of activated carbon from coals usually involves the utilization of steam at similar conditions. Combining these two processes would lead to the simultaneous production of both energy and a specialty product from low reactivity coal. Low reactivity coals with low volatile matter content are ideal feedstocks for this concept. This is because the carbonization step can essentially be eliminated, while a good recovery of activated carbon can be achieved. In addition, there is substantial advantage of operating a gasifier with no ash or slag removal.

This concept was initially explored by Gulf Canada and threshold costs were established, given the provision that power generation costs need to be compatible with local power grid costs. Earlier studies had also identified process options which could be used in pilot plant operation, and product qualities attainable had been quantified in autoclave systems.

This current research contract had the following objectives:

- Review recent technology for the production of activated carbons.
- Review market assessments for activated carbons and identify potential applications for the pilot plant material.
- Assess the Mt. Klappan development and integrate the technology of activated carbon production into the plant development profile.
- Acquire and prepare appropriate samples of Mt. Klappan anthracite.
- Design and construct an experimental pilot plant and carry out a series of pilot scale tests.
- Assess the activated carbon and gases produced and develop product application tests for specific product applications.
- Provide an Engineering assessment and preliminary cost analysis for full scale activated carbon production within the Mt. Klappan plant concept.

The work performed to complete these objectives is described in the following sections.

3.0 PRODUCTION OF ACTIVATED CARBON FROM MOUNT KLAPPAN

A number of options for the supply of power to the Mt. Klappan Mine have been studied by Gulf. One of these was the on-site production of power with the excess power being supplied to the B.C. grid.

A detailed analysis of this option showed that projected levelized cost of power for a commercial plant was in the range of 4.3 to 5.1 cents/kWh. This was compared to a levelized cost of 3.6 cents/kWh for future hydro developments.

The current program of technology development and commercial assessments was designed to see if an alternative to the integrated gasification combined cycle case could be developed. The intent was to effectively decrease the cost of power production by providing a high value marketable product while simultaneously producing gas for power generation.

As far as possible, in the economic calculations, the data used in the Gulf IGCC study were incorporated in to the activated carbon study.

4.0 LITERATURE REVIEW OF PRODUCTION AND UTILIZATION TECHNOLOGIES FOR ACTIVATED CARBONS

Recent technology development in the production and utilization of activated carbons was reviewed in Task 1 of this research contract. The literature review report is presented in Appendix 1. Six data bases were used in this literature review, and a research report on the treatment of drinking water by activated carbon was also provided by Gulf Canada. This literature review shows the following:

4.1 Effects of Operating Conditions on Activated Carbons

A review of the influence of process variables shows that high activation temperature and longer residence time lead to the production of micropores. However, a shift from micro to meso pores is observed as carbon burnoff progresses. Alkali additives have been used to enhance reactivity and increase surface areas. Activated carbons from anthracites are predominantly microporous in structure because of the nature of the feedstock and the high temperatures required for the activation process.

4.2 Production Technologies and Reactors

While industrial reactors such as rotary kilns, vertical retorts, and shaft kilns are available, the fluidized bed reactor is most suitable for processing anthracite for the production of activated carbon. The fluidized bed reactor offers uniform treatment of individual particles, good gas-solids contact, and good heat transfer behaviour. A fluidized bed process was developed in the 1960's in the U.K. for anthracite by the National Coal Board and was subsequently put into commercial operation by Thomas Ness Limited. The same technology has also been extensively tested in a demonstration scale of 200 kg capacity in the Institute of Gas in USSR. Data showing material consumptions are documented in this literature review. It should be noted that the fluidized bed reactor was operated in a batch mode to control the residence time of the

activation process.

4.3 Utilization Technologies

Recent developments in the utilization of activated carbon concentrated in granular forms and carbons impregnated with chemicals. The use of chemicals can significantly expand the utilization of activated carbon through mechanisms of chemical sorption/reaction, in addition to the physical sorption mechanism available from the large surface areas. All these new applications have been well developed; and commercial installations are already in place. The most important technology developments for the utilization of activated carbon are as follows:

- SO_2 and NOx removal from flue gas
- purification of landfill gases by pressure swing technique
- low grade gold recovery
- treatment of drinking water

Bio-remediation using activated carbon has been well documented in the literature on waste water treatment. Bacteria adsorbed on activated carbon can partially regenerate the carbon column, making the use of granular activated carbon (GAC) more cost-effective. The performance of GAC based on combined adsorption and biodegradation was reported to be more stable and reliable. Powdered activated carbon has also been used as a controlling mechanism for the activated sludge process.

5.0 COAL SAMPLE ANALYSIS

In this study Mt. Klappan coal was used as feedstock for activated carbon production using steam gasification. The coal was anthracite by rank. The coal, as used in these experiments was air dried, crushed and screened to provide samples of 8 to 16 mesh, 20 to 40 mesh, 30 to 50 mesh and less than 16 mesh particle sizes. The 20 to 40 mesh sample was feedstock remaining from the previous fixed bed program. Proximate and ultimate analyses of the coal samples are presented in Table 5.1.

TABLE 5.1 COAL PROXIMATE AND ULTIMATE ANALYSES

Coal	Mt. Klappan			
Mesh Size	8-16	20-40	30-50	-16
Proximate (wt%, as rec'd)				
moisture	2.4	3.1	3.5	2.9
ash	6.9	7.4	6.4	6.9
volatiles	6.3	4.5	4.7	5.6
fixed carbon	84.4	85.0	85.4	84.6
Ultimate (wt%, daf)				
C	94.6	94.5	not determined	
H	3.0	3.1		
N	1.2	1.4		
S	0.4	0.5		
O (by difference)	0.8	0.5		

6.0 PILOT-SCALE REACTOR DESIGN, CONSTRUCTION AND COMMISSIONING

6.1 System Design and Components

The site chosen for construction of the unit was the Alberta Research Council's Nisku Interim High Pressure Facility. The design of the unit was based on a fluidized bed reactor that had been used previously for coal gasification at the Chemical Engineering Department at the University of British Columbia. The reactor was a 1 meter high by 16 cm diameter fluidized section topped with a 27 cm high by 25 cm diameter disengaging section. The original design concept called for a maximum coal feed batch of 10 kg and reactor bed temperatures up to 1000°C.

After obtaining the reactor from the University of British Columbia, it was determined that modifications to the existing furnace were necessary in order to accommodate the reactor. Furnace elements 18 cm in diameter and 46 cm long with 2820 W power rating were purchased and used to replace the elements in the top two furnace sections. The elements in the bottom section of the furnace were replaced with 13 cm diameter, 61 cm long, 3770 Watt furnace elements. The bottom elements had a temperature rating of 1204°C, while the top two furnace sections had a temperature rating of 1010°C.

The existing high pressure nitrogen/hydrogen supply was modified to provide a low pressure nitrogen supply only. An existing Gilson Metering Pump, Model #302, with 50 ml/min feed capacity was used for the water supply. The lower zone of the reactor furnace held a 12 meter long, 6 mm stainless steel tubing coil for preheating the inlet nitrogen and steam. A coal feed silo was constructed and installed above the reactor to hold the feed coal batch. A carbon product receiver was installed below the reactor to collect solid products at the completion of an experiment. The coal silo, reactor, and the receiver were equipped with nitrogen purge capability.

The outlet of the reactor was equipped with a cyclone for primary entrained solids removal followed by a Type 30/25 Balston filter, which collected any entrained solid matter that was not collected by the cyclone. The gas then passed through a condenser to remove any unreacted steam from the gas flow. The dried gas then flowed through a 1/3 psi Nupro check valve, which maintained positive pressure throughout the system, then through an existing Singer Dry Gas Meter and proceeded to the process vent in the cell. The sample line for gas analysis was just upstream of the check valve. An existing Hewlett Packard 5890 II Gas Chromatograph with a 3396 A Integrator was used for gas analysis.

All temperature transducers used were type K thermocouples. Three thermocouples were used for furnace temperature control, one monitored the temperature at the top of the reactor for emergency shut-down, and one was used to monitor and regulate the heat tracing on the cyclone. Six thermocouples were used to measure the bed temperatures in the reactor, and thermocouples were used to monitor the temperatures of gas leaving the cyclone, of gas leaving the condenser, and of gas entering the dry gas meter. There were three pressure transducers: one measuring coal silo pressure, one measuring reactor pressure, and one measuring the nitrogen supply pressure. All transducers were connected via existing wiring inside the cell to existing instrumentation on the cell's control panel. In addition the thermocouples inside the reactor and the reactor pressure transducer were connected to an existing Acurex Autodata Ten/10 Datalogger which monitored and periodically recorded the temperatures and pressure inside the reactor. The Datalogger was also capable of providing an emergency shut down feature, which automatically shut down the system if the pressure rose into alarm. The unit was also equipped with pressure relief valves to prevent the system pressure from exceeding 10 psig. A process and instrumentation diagram of the unit is shown in Figure 6.1.

6.2 Commissioning

After several preliminary experiments on the UBC reactor it was determined that gas tightness could not be maintained and the construction of a new reactor was undertaken. The new reactor was of identical dimensions to the UBC reactor but was of all welded construction and was manufactured by the University of Alberta's Technical Services. Leak tests using the new reactor were successful.

Initially, based on UBC data and previous fixed bed experiments, it was thought that a nitrogen flow rate of 50 standard liters per minute combined with a water flow rate of 10 ml/minute would be adequate for the activation of 10 kg of coal. Attempts to gasify a coal charge of this size were unsuccessful due to insufficient water/steam flow and low bed temperatures. These problems were solved by the addition of another 12 m preheat coil and an additional water feed pump while simultaneously reducing the input coal mass. The revised system could provide steam to the reactor inlet at temperatures over 1100°C and up to 70 g/min. With this modified design it was found that input coal charges of up to 2 kg could be successfully activated with a steam flow rate of 55 g/min combined with 5 standard litres per minute of nitrogen. Reactor bed temperatures could be controlled in the desired range of 900°C to 950°C by controlling the preheat temperatures.

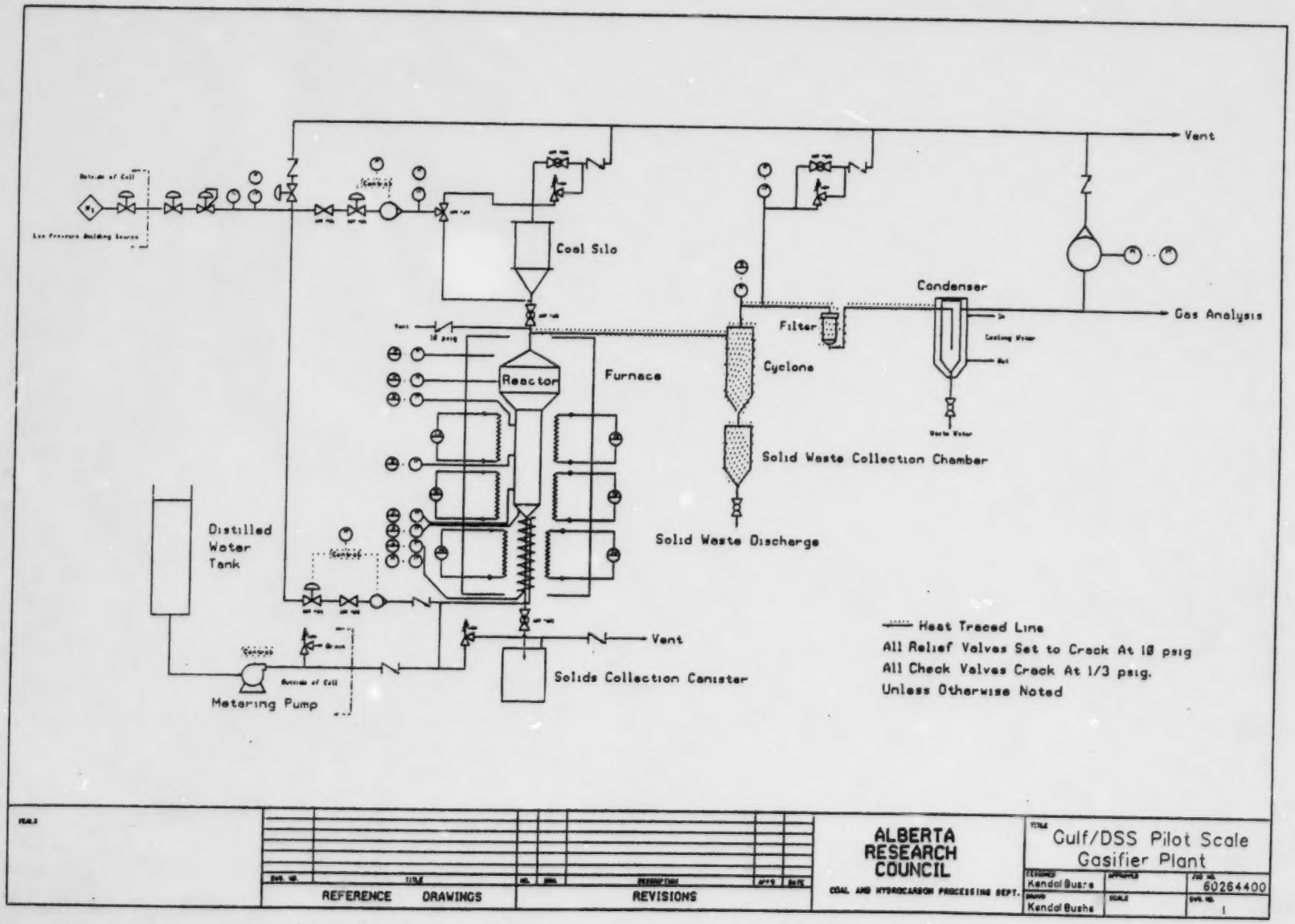


FIGURE 6.1 GULF/DSS PILOT SCALE GASIFIER PLANT

7.0 PILOT TESTING PROCEDURES

This section describes the experimental procedures used for the carbonization (charring), gasification and activation experiments, and the procedures used for gas analyses and product solids analyses (proximate analyses, surface area and pore size analyses). A flow chart, Figure 7.1, shows the sequence of experiments and analyses used in this work.

7.1 Activation Experiments

The activation experimental technique consisted of a heat up step, in an inert gas stream (nitrogen), followed by reaction/activation in steam. The heat up step was used in order to achieve stable and controllable reactor temperatures and to facilitate the release of volatile matter from the coal.

A one or two kilogram sample of coal was placed in the coal silo. The coal was carried into the preheated reactor using an inert gas carrier (nitrogen). The sample was held in the reactor until the desired reaction temperature was reached in the coal bed, 900 or 950°C, in the nitrogen stream (5 slpm) to remove the volatile matter. The steam was then introduced flowing through the coal sample at a rate 55 g/min (steam gasification/activation step).

The product gases were collected continuously during the reaction with steam. The total time of reaction with steam varied from about 90 to 180 minutes, as dictated by the conversion levels desired. Conversion targets were in the range of 50 to 75 wt% of the input carbon. The approximate conversion was calculated during the experiment based on the carbon exiting the reactor in the product gases. The steam flow was terminated once the conversion target had been reached. At the conclusion of the experiment the unreacted solids in the reactor were cooled in a nitrogen stream and transferred to the product receiver. The cooled product was removed from the receiver

and its weight was recorded. This 'activated carbon' product was subsequently analysed to determine its ash and unreacted carbon content using a thermogravimetric analyser. The solid products were also analysed for nitrogen surface area and pore size distribution and submitted to the University of Alberta for commercial analyses (see Section 9.0). The gas samples were analysed by gas chromatograph to determine product gas quantities and compositions. The solids from the cyclone and filter and the water collected in the condenser were weighed to complete the mass balances.

7.2 Activated Carbon Analyses

The product solids (activated carbons) were analysed to determine product quantities and qualities. The analytical techniques used were:

a. Proximate Analysis

The proximate analyses of the coals and activated carbons were performed using a Dupont thermogravimetric analyser (TGA). This technique was used because it uses small quantities of sample (~10 mg). The conditions used were as follows: the sample is heated to 900°C in nitrogen flowing at 100 ml/min, the sample is held at 900°C in nitrogen for 3 minutes at which time the nitrogen is switched to air and the sample is oxidized in the 100 ml/min air flow for about 15 minutes (until no further weight loss is observed). The weight of the sample is monitored continuously and at the conclusion of the test the moisture, volatile matter, fixed carbon and ash content of the sample can be determined.

b. Surface Area and Pore Size Analyses

Surface areas and porosities of active carbons are determined by an automated system (Micromeritics, Digisorb 2600) at the Alberta Research Council's Coal and Hydrocarbon Processing Department. This system is of the volumetric type and is

capable of analyzing five samples sequentially. The generalized procedure employed is outlined below.

1. Sample Preparation

Active carbons have relatively high surface areas (500 - 1000 m^2/g) and extensive testing of these materials has shown that about 0.2 g of material can be accurately weighed and analyzed reproducibly (±5%). The samples of active carbons are generally degassed at 300°C for two hours in vacuum to a pressure of 10^{-3} torr which ensures the removal of adsorbed gases and water trapped in the micropores. Following degassing, helium gas is admitted, the dry sample weight is obtained and the samples are ready for measurement of the adsorption isotherms.

2. Isotherm Measurement

The samples are first evacuated at room temperature at a pressure of 10^{-3} torr for two hours, which is sufficient to remove the helium admitted to the sample in the preparations step. The samples are then immersed in liquid nitrogen and the dead volume determined for each sample by helium. The saturation vapour pressure of the nitrogen adsorbate is determined directly by pressure measurement in a condensation tube and this measurement is repeated approximately every 30 minutes during the determination of the adsorption isotherm. The isotherm is determined at present relative pressures (vapour pressure/saturation vapour pressure) between 0.05 and 0.995. Some measurements at lower relative pressures are obtained when the total uptake of gas exceeds 50 cm^3/g (STP) at 0.05 relative pressure. The isotherm determination proceeds for each sample in turn.

3. Surface Area/Porosity Calculation

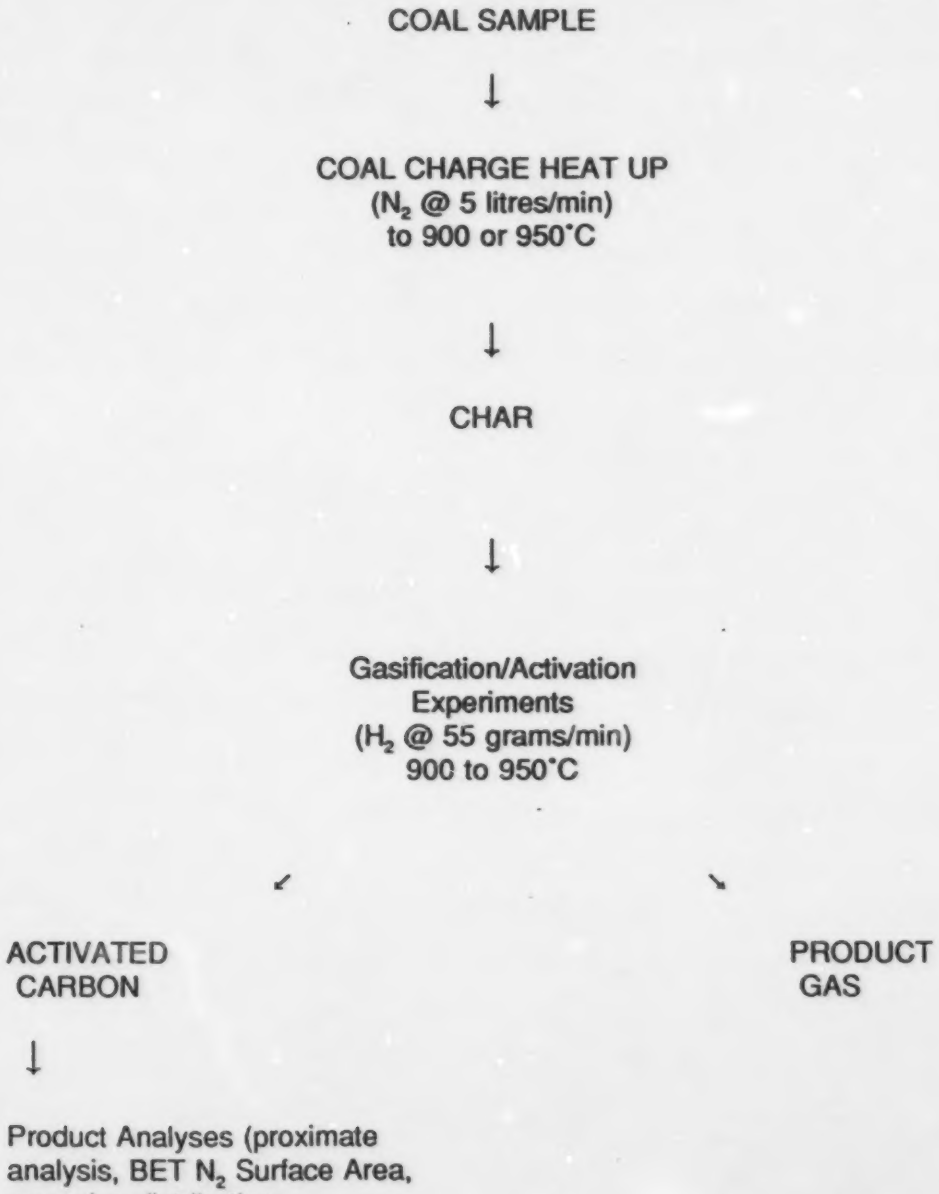
The surface area is calculated by the BET method for adsorption at relative

pressure between 0.05 and 0.21. Porosity is treated by use of the Kelvin equation and the assumption of straight, parallel cylindrical pores opened to both ends. Suitable values are taken for the surface tension and contact angle of liquid nitrogen (8.85 ergs/cm^2 and 0, respectively). The pore size distribution is computed according to the methodology of Barrett, Joyner and Halenda[1] (BJH method) for adsorption and desorption branches of the isotherms as specified. Tables are provided of pore size interval (r_1 to r_2) versus pore volume and also pore area. It is important to realize that pore area is calculated assuming cylindrical pores and that any agreement between BET (or Langmuir) surface area and total pore area is coincidental. Additionally, the application of the BJH method is valid only for the so called Type IV isotherm which is hardly ever exhibited by active carbons which are mostly microporous. However, as yet no method exists for the determination of microporosity distribution from a single isotherm.

7.3 Product Gas Analysis

The product gases produced during the steam gasification stage were analysed at 13 minute intervals throughout the activation experiment. The total volume of gas produced was measured using a Singer gas meter. The product gases were then analysed for composition using a Hewlett Packard 5890 II Gas Chromatograph with molecular sieve and Poropac Q separation columns and a thermoconductivity detector. From the volume and composition data quantities of all product gas components could be calculated. These values were used for subsequent mass balance determinations and product gas heating value estimation.

FIGURE 7.1 FLOWCHART OF EXPERIMENTAL PROCEDURE AND ANALYSES



8.0 RESULTS OF ACTIVATION EXPERIMENTS

Gasification and activation experiments were performed in accordance with the experimental procedures discussed in Section 7. Both the solid product (activated carbon) and the gaseous product were analyzed and characterized for qualities. The results of the BET N_2 measurements for all the carbon products are included in Appendix I.

Table 8.1 shows the results of gasification and activation of Mt. Klappan anthracite. The Table presents operating conditions, carbon conversions, overall mass balances, and the qualities of the products. As can be seen, mass balances were in the 96 - 103% range.

8.1 Surface Area and Char Conversion

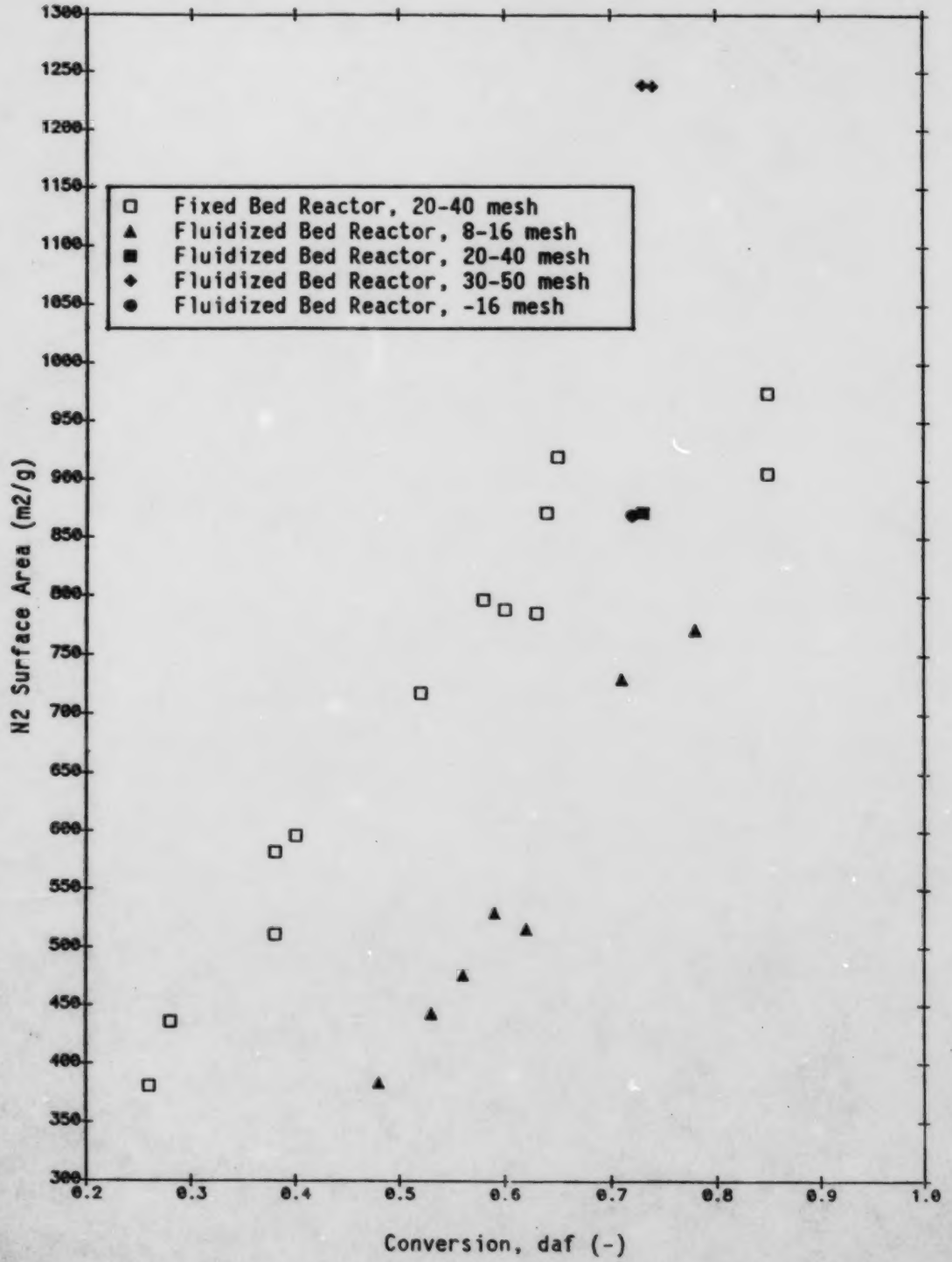
In Figure 8.1, the data from Table 8.1 was compared to the data obtained in 1989 using 20-40 mesh particle sizes of the same coal (B.Y. Wong, G. Kovacik). It can be seen that the higher carbon conversion led to higher surface area, however, one point stood out as an exception. The high carbon conversion of run MTK-0722 gave a surface area similar to surface areas found in runs having much lower carbon conversion. The cause of this discrepancy was not explainable, and, for further analysis, this experimental result was disregarded. The result for the 20-40 mesh coal in the fluidized bed reactor compares closely to the data for the same coal in the previous fixed bed reactor studies.

Table 8.1 Experimental Results for Mt. Klappan Coal (Heating in Nitrogen, Steam Activation)

	Conditions				Gas Analysis			Activated Carbon		
Run #	Feed Wt. (g)	Mesh Size	Temp. (°C)	Res. Time (min)	CO	H_2 (mol%)	CO_2 (m^2/g)	S.Area BET N_2	Conv. daf	Mass Balance (m_{out}/m_{in})
MTK-0715	1000	8-16	937	90		not analyzed		476	56	n/a
MTK-0717	1000	8-16	937	84		not analyzed		443	53	n/a
MTK-0722	1000	8-16	940	120	39	54	7	451	74	0.968
MTK-0724	2000	8-16	905	120	42	51	7	384	48	0.992
MTK-0729	2000	8-16	910	180	45	48	7	730	71	0.861*
MTK-0807	2000	8-16	900	160	40	51	9	516	61	0.969
MTK-0813	1000	8-16	947	120	40	51	9	772	78	1.018
MTK-0822	840	20-40	950	100	34	57	9	842	72	0.974
MTK-0828	2000	8-16	890	150	41	54	7	530	60	0.984
MTK-1016	1910	30-50	950	150	34	56	10	1239	73	1.121
MTK-1018	2025	30-50	950	165	40	53	7	1238	75	1.026
MTK-1023	2010	-16	900	170	40	53	7	870	72	1.025

* Product gas meter failure

Figure 8.1 Mt. Klappan Activated Carbon Surface Area Variability with Carbon Conversion



8.2 Pore Size Distributions of Activated Carbon

The properties of the product activated carbon that were measured in this study were ash content, nitrogen surface area (BET), pore volume, and pore size distribution. Table 8.2 summarizes the pore volumes and pore size distributions for selected carbons. Pore size distributions determine the proportions of micro pores (<20 A), meso pore (20-50 A), and macro pores (>50 A) in the activated carbons. As can be seen, the surface area, pore volume and pore size distribution of the Mt. Klappan carbons compared fairly closely with the Filtrasorb 300 carbon, which is produced by Calgon Carbon Corporation from bituminous coal for drinking water treatment applications. The Filtrasorb had somewhat higher percentage of macropores and a lower ash content. The GRC 22 carbon is marketed for gold recovery applications and was produced from coconut shells. This carbon had the vast majority of its pore volume concentrated in the micropore range and a very low ash content.

Table 8.2 shows that the pore structures of activated carbon from Mt. Klappan coal are predominantly micropores. However, the data also show that as char conversions increased, the proportion of meso pores increased at the expense of micropores. This data indicates that as the conversion of char increases, the micropores begin to enlarge and this results in the higher proportions of meso pores in the activated carbons. As char conversion is related to both reaction temperature and residence time, higher reaction temperature and longer residence time should favor the development of meso pores. This observation was also made in the previous smaller scale fixed bed reactor studies.

8.3 Properties of Product Gas

The properties of the product gas that were measured in this study were gas composition and amount. The product gas analyses for the activation experiments are summarized in Table 8.1. The amount of gas produced was directly proportional to the

level of conversion. The product gas composition did not vary greatly over the conditions tested, carbon monoxide 34-45 vol%, hydrogen 48-57 vol% and carbon dioxide 7-10 vol% on a dry basis. These product gas compositions compare very closely to those obtained in the smaller unit previously where dry product gas concentrations of carbon monoxide 30-40 vol%, hydrogen 49-56 vol%, and carbon dioxide 6-14 vol%, were measured. The changes in composition, which occurred, were due to the equilibrium properties of the gas mixture. The gas heating value was relatively constant, 10-11 MJ/m^3 higher heating value, for all conditions tested. This was due to the fact that the heating value of hydrogen and carbon monoxide are almost equal and the gas composition did not vary significantly.

Table 8.2 Pore Volumes and Pore Size Distributions for Activated Carbons

	Conditions				Activated Carbon Properties				
Carbon Type	Mesh Size	Temp. (°C)	Res. Time (min)	Ash Content (wt%)	S.Area BET N_2 (m^2/g)	Pore Vol. (ml/g)	% Micro <20A	Pore Meso 20-50A	Size Dist. Macro >50A
Mt. Klappan Carbons									
MTK-0822	20-40	950	100	16	842	0.45	79	16	5
MTK-1018	30-50	950	165	19	1238	0.63	82	14	4
MTK-1023	-16	900	170	19	870	0.44	83	13	4
MT-49*	20-40	950	90	12	872	0.44	78	17	5
Commercial Carbons									
GRC 22**				3	1050	0.51	94	4	2
Filtrasorb 300***				10	1018	0.60	73	10	17

* From previous work with fixed bed reactor

** Gold recovery carbon produced by Calgon Carbon Corp.

*** Water treatment carbon produced by Calgon Carbon Corp.

8.4 Effect of Particle Size

The effect of the coal particle size on the product qualities for the Mt. Klappan activated carbons is summarized in Table 8.3. As can be seen in this table, and in Figure 8.1, a decrease in particle size from 8-16 mesh to 30-50 mesh results in almost doubling the BET surface area at equivalent conversion levels. The particle size had little effect on the product gas composition.

It can be seen that larger particle sizes of coal gave lower surface area carbons. This could be explained by the fact that smaller particles will inherently have larger specific surface areas. By providing the same proportional increase in surface area to a finer coal particle, more specific surface area would be generated.

Several models predicting surface area from carbon conversion have been examined, including the random pore model of Bhatia, Perlmutter and Gavalas. Some work has been done on attempting to fit a mathematical model to the available data. This work has concentrated primarily on the integration over time of a rate equation involving the variables of carbon conversion, pressure, temperature, steam partial pressure, and run duration. This work has been hindered by a lack of sufficient data. Currently, a suitable mathematical model for the prediction of carbon conversion has yet to be found, however, work in this area is continuing. Regardless, it is evident from the data that carbon conversion, and therefore, surface area and pore size distribution was highly dependant on temperature and residence time.

Table 8.3 Effect of Particle Size for Mt. Klappan Activated Carbons

Carbon	Mesh Size	Temp (°C)	Res. Time (min)	Carbon Conv. (wt%)	S. Area BET N_2 (m^2/g)	Pore Vol. (ml/g)	Product Gas CO	H_2	Analyses CO_2 (mol%)
MTK-0813	8-16	947	120	78	772	0.43	40	51	9
MTK-0822	20-40	950	100	72	842	0.45	34	57	9
MTK-1018	30-50	950	165	73	1238	0.63	34	56	10
MTK-1023	-16	900	170	72	870	0.44	40	53	7
MT-49*	20-40	950	90	64	872	0.44	40	54	6

* From previous work with fixed bed reactor

9.0 CHARACTERIZATION OF ACTIVATED CARBONS

Four samples of activated carbons produced from Mt. Klappan anthracite, with BET surface areas ranging from 772 to 1,239 M^2/gm, were selected and characterized for water and waste water treatment, gold recovery, and sorption of sulfur dioxide. Two commercial activated carbons, the Filtrasorb 300 (for water treatment) and GRC-22 (for gold recovery), were tested concurrently to generate comparative data. The methods of characterization are described below and the procedures used are presented in the appendices for reference.

9.1 Water and Waste Water Characterization

The standard tests performed for water characterization included the determinations of Iodine Number, methylene blue number, modified phenol value, and tannin value. A non-standard test, the determination of Mesitylene value, was also performed to assess the ability of the carbons for odour removal. All these tests were performed at the Environmental Engineering and Science Laboratory at the University of Alberta. The complete report, from the University of Alberta, is included in Appendix II.

9.1.1 Significance of Tests

Iodine Number

The Iodine Number is an index of the adsorption capacity for low molecular weight compounds. This index usually follows the surface area as determined by BET method. A minimum value of 500 mg/gm is suggested by the American Water Works Association (AWWA) for powdered activated carbons (PAC) used for water and waste water treatment.

Methylene Blue Number

The Methylene Blue Number (g/100 gm carbon), on the other hand, is an index of the adsorption capacity for high molecular weight compounds such as Methylene Blue ($C_{16}H_{18}N_3SCl$).

Modified Phenol Value

The modified phenol value is an index of the adsorption capacity for polar, ionic and low molecular weight organic compounds. As the phenol value test is defined as the dosage of carbon required to remove 90% of a 200 mg/L phenol solution, a low value indicates a high sorption capacity. The AWWA suggests a maximum value of 3.5 g/L for this index.

Tannin Value

The tannin value is an index of the adsorption capacity for very large and complex organic compounds, such as tannic acid ($C7_{76}H_{58}0_{46}$). It is used as an indicator for the adsorption of aquatic humic substance and color-imparting organic compounds. It is defined as the carbon dosage required to remove 90% of a 20 mg/L tannic acid solution, and a lower value indicates a higher sorption capacity. A value of 270 mg/L or lower is suggested for effective removal of high molecular weight organics.

Mesitylene Value

Mesitylene (1,2,5 trimethyl benzene) is a non-polar, aromatic hydrocarbon with an odour threshold concentration of 3 Ug/L. This index is defined as the dosage of carbon required to remove 90% of a 10 mg/L mesitylene solution. As such, a low value (mg/L) indicates a high adsorption capacity.

The mesitylene value is not a standard test. Furthermore, mesitylene is highly volatile and a higher variance is usually observed in the test results. Nevertheless, this test was performed to compare the performance of the carbons produced in this project with commercial product for odour removal.

9.1.2 Test Procedures

All the activated carbons characterized for water and waste water treatment were first reduced to a top size of 325 mesh, the particle size of powdered activated carbon (PAC). They were dried at 150°C overnight prior to characterization.

The following procedures were used:

• Iodine Number	AWWA B600-78
• Methylene Blue Number	EPA 625/1-71-002a
• Modified Phenol Value	AWWA B600-78
• Tannin Number	AWWA B600-78
• Mesitylene Number	Method described by Troxler, "Powdered Activated Carbon Selection-University of Alberta Technical Report 88-1"

9.2 Characterization for Gold Sorption

The two most important criteria in applying activated carbons for gold recovery are the adsorption rate (R value, hr^{-1}) and the adsorption capacity (mg/gm). It is generally accepted that the rate is a more important factor than the sorption capacity in actual operation. Another factor critical in actual operation is the attrition characteristics of the carbons. This factor, however, can only be meaningfully determined when a large quantity of samples is available.

The activated carbon samples were characterized without any reduction of particle size (30 - 50 Mesh). Activated carbons were immersed in a gold solution for four hours and the residual gold concentrations of the solution were determined at various time intervals for sorption rate and equilibrium sorption capacity. The testing follows the method by Faulkner, as outlined in the paper entitled "Activated Carbon for Precious Metals Recovery, Society of Mining and the Metallurgical Society 110th Annual Meeting".

9.3 Characterization for Sorption of Sulfur Dioxide

The sorption of sulfur dioxide was characterized by determining the weight gain of the activated carbons by passing a stream of nitrogen containing sulfur dioxide. A TGA (Thermogravimetric analysis) technique was used in this characterization. The coal-based Calgon product "Filtrasorb 300" was again used to generate comparative data.

The Mt. Klappan activated carbons were evaluated for both the original particle size (30 - 50 mesh) and at a top size of 325 mesh. An activated carbon sample in a TGA chamber was tested by passing a gas stream of nitrogen containing 2,800 ppm of SO_2 at a flow rate of 100 ml/min. Two sorption temperatures of 25°C and 180°C and a total duration of usually 120 minutes were used in these sorption experiments.

10.0 PRELIMINARY EVALUATION OF PRODUCT APPLICATIONS

The results of the characterization tests are used to assess product applications for water and waste water treatment, gold recovery, and removal of sulfur dioxide from flue gas. During product characterization, different sorption behaviours were observed for activated carbons produced from different processes, and these behaviours cannot be satisfactorily explained by surface area and pore size distributions. The surface chemistry of the activated carbons appears to be a cause for these different sorption behaviours.

10.1 Water and Waste Water Treatment

The results of water treatment characterization tests are presented in Table 10.1. It was observed that the Iodine numbers of all the Mt. Klappan activated carbons exceed the minimum value of 500 mg/gm suggested by the AWWA. The Iodine numbers also follow their BET surface areas but their absolute values are usually less than those of the surface areas. The Iodine number of Filtrasorb 300, on the other hand, was higher than the value of the surface area. Because of this inconsistency, Filtrasorb 300 and MTK-1023 show similar Iodine numbers (1087 vs 1051) while the MTK-1023 is about 200 units higher in BET surface area than Filtrasorb 300.

The methylene blue numbers showed that the magnitude of this number is proportional to the surface areas. However, the methylene blue numbers for MTK-1023 (24.68) and Filtrasorb 300 (24.56) are virtually the same, despite a difference in the surface area values by 200 units.

These two tests suggest that under the broad definition of molecular sizes, without considering the nature of the organic compounds, the activated carbons from Mt. Klappan with higher surface area should perform equally well as the commercial product Filtrasorb 300.

Table 10.1 Water and Waste Water Characterization

Summary of Results

Carbon Sample	Surface Area (m2/g)	Iodine Number (mg/g)	Methylene Blue Number (g/100g carbon)	Modified Phenol Value (g/L)	Mesitylene Value (mg/L)	Tann-in Val-ue (mg/L)
MTK-0813	772	744(±9)	16.76 (±0.13)	3.98	50.6	1375
MTK-0822	871	783(±8)	17.71 (±0.02)	3.91	37.0	1032
MTK-1016	1239	1051 (±11)	24.68 (±0.26)	2.67	21.6	1525
MTK-1023	870	802(±2)	17.54 (±0.14)	3.34	27.8	1376
Filtrasorb 300	1018	1087 (±10)	24.56 (±0.10)	1.73	11.0	273

The modified phenol number, the mesitylene value, and the tannin value can be considered as a more specific indication of the affinity of carbons for small polar compounds, large complex molecules, and odor generating aromatic species, respectively. Although two of Mt. Klappan activated carbons exhibited a modified phenol value of less than 3.5 g/L, they are substantially higher than the value determined for Filtrasorb 300 (1.73). The mesitylene numbers for all the Mt. Klappan activated carbons are substantially higher than the value of Filtrasorb 300, suggesting the Mt. Klappan carbons are less effective in the removal of odour generating aromatic species.

The tannin values determined in the characterization program showed that there is a significant difference in this parameter between the Mt. Klappan activated carbons and Filtrasorb 300 (1000 + vs 273). This test indicated that the Mt. Klappan activated carbons are less efficient in the sorption of large and complex organic compounds.

10.2 Gold Recovery

The results of gold sorption rate and capacity for Mt. Klappan activated carbons and GRC-22 are presented in Table 10.2. It was observed that both the sorption rate and sorption capacity showed excellent correlation with the surface area, when all the activated carbons were produced from the same process (Figures 10.1 and 10.2). The sorption rate and capacity data of GRC-22 did not follow the trend lines established for the Mt. Klappan activated carbons.

All the activated carbons produced from Mt. Klappan showed a higher rate of sorption than GRC-22, even when the surface areas are substantially lower. MTK-1016, in particular, showed a sorption rate significantly higher than GRC-22 (14.65 hr^{-1} vs 3.95 hr^{-1}). However, all the Mt. Klappan activated carbons showed a lower equilibrium sorption capacity than GRC-22. A sorption capacity of 28.8 mg/g was achieved by sample MTK-1016, as compared to a value of 36.6 mg/g shown by the GRC-22 coconut-based activated carbon.

Table 10.2 Gold Sorption Characterization

Summary of Results

Carbon Sample	Surface Area (m^2/g)	Gold Adsorption Rate (R Value)	Gold Adsorption Capacity (K Value) (mg/g)
MTK-0813	772	5.94	18.8
MTK-0822	871	5.28	20.6
MTK-1015	1239	14.65	28.8
MTK-1023	870	6.27	24.2
Calgon GRC-22	1050	3.95	36.6

Figure 10.1 Effect of Surface Area on Gold Adsorption Rate

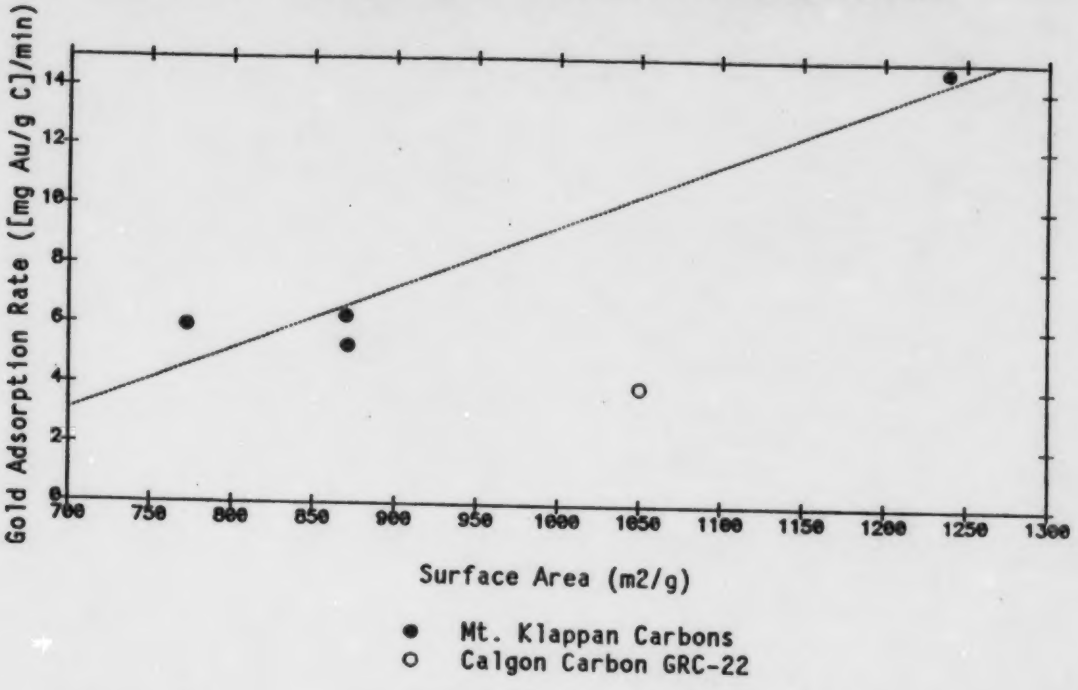
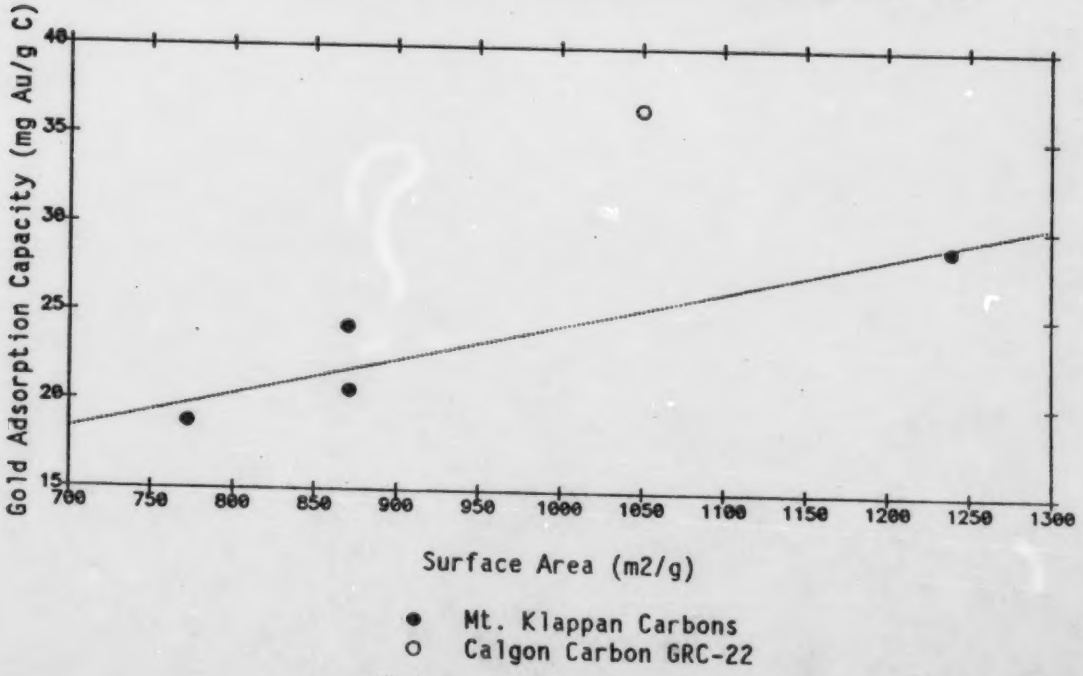


Figure 10.2 Effect of Surface Area on Gold Adsorption Capacity



These preliminary data indicate that the activated carbons produced from this project have characteristics suitable for the application of gold recovery. These carbons showed a higher sorption rate but a lower sorption capacity than the commercial product (GRC-22) used in this application. The difference of the sorption behaviours observed by two different types of carbons, however, cannot be explained by the available data.

10.3 Sorption of Sulfur Dioxide

The results of sulfur dioxide sorption tests are summarized in Table 10.3. This data showed that sorption capacity is significantly affected by sorption temperature. Low temperature is favorable for sorption and high temperature is favorable for desorption.

Sorption experiments conducted on the same samples but different particle sizes only showed small variations in the test results.

Since Filtrasorb 300 is only available in the top size of 325 mesh, the sorption capacities for Mt. Klappan activated carbons of this top size are compared with Filtrasorb and related to their surface area in Figure 10.3. This data showed that the sorption capacity of Filtrasorb is higher than those from the Mt. Klappan activated carbons produced from this research project. From Figure 10.3, the sorption capacity for sulfur dioxide, at 25°C, was proportional to the surface area of the Mt. Klappan carbons.

Table 10.3 Sulfur Dioxide Adsorption Characterization

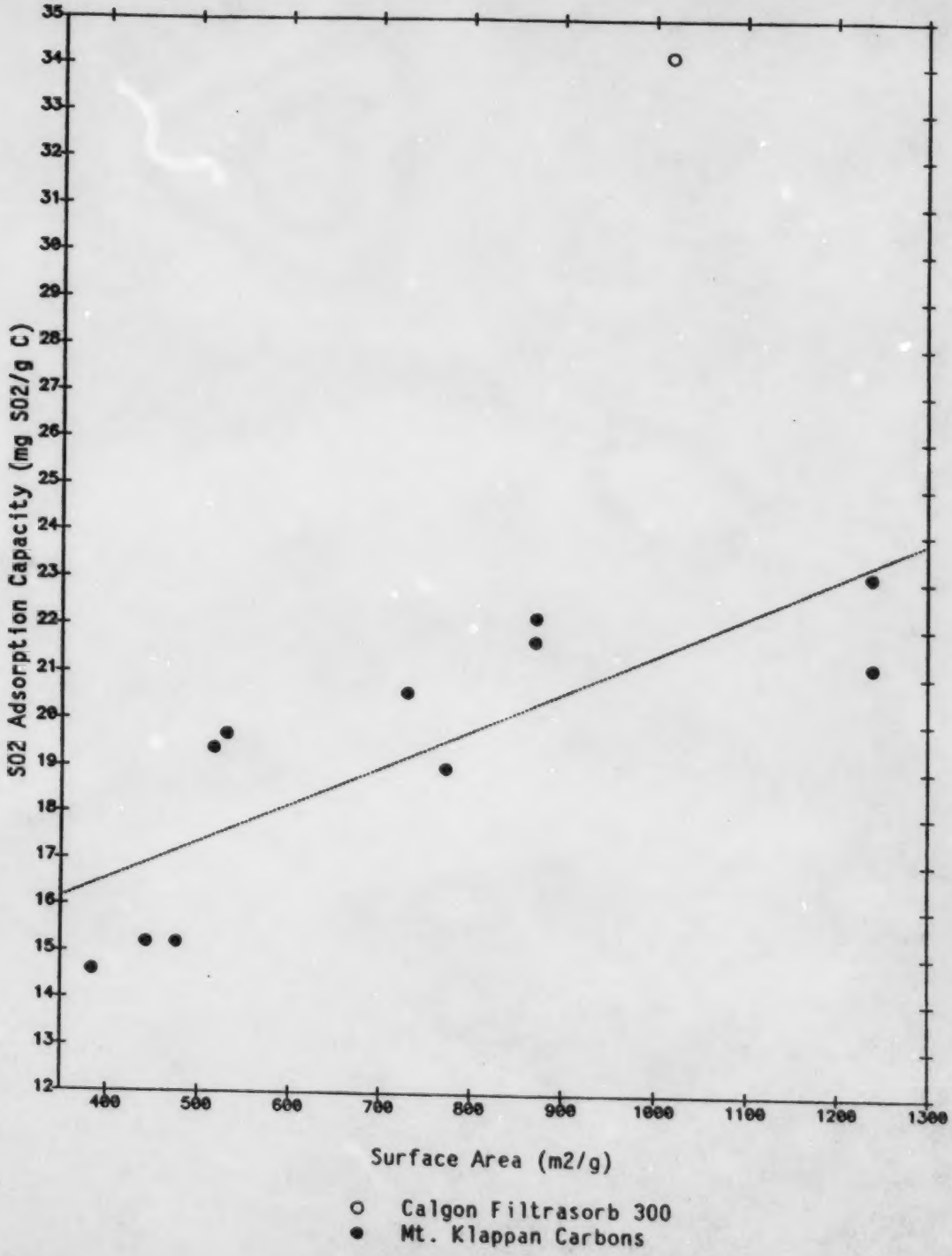
Summary of Results

Sample	BET Surface Area (m2/g)	Temperature (C)	% Moisture	Adsorbed Weight(mg/g)
Filtrasorb 300-325M	1018	25	0.79	34.24
MTK0822-325M	871	25	0.60	27.85
MTK1023-325M	870	25	11.67	26.41
MTK1016-325M	1239	25	0.45	24.91
MTK1023-16M	870	25	0.37	24.70
MTK1018-30+50M	1238	25	0.09	23.08
MTK0822-20+40M	871	25	0.36	22.20
MTK1023-16M	870	25	0.23	21.70
MTK1016-30+50M	1239	25	0.06	21.24
MTK0813-325M	772	25	0.58	21.20
MTK0729-16+24M	730	25	0.39	20.55
MTK0828-16+24M	530	25	0.24	19.69
MTK0807-16+24M	516	25	0.52	19.37
MTK0813-16+24M	772	25	0.41	18.97
MTK0717-16+24M	443	25	0.27	15.32
MTK0715-16+24M	476	25	0.21	15.27

Table 10.3 Continued

MTK0722-16+24M	451	25	0.23	10.29
MTK1023-16M	870	180	0.17	4.26
MTK1016-30+50M	1239	180	0.15	4.16
MTK0822-20+40M	871	180	0.29	3.65
MTK1023-16M	870	180	0.32	3.13
MTK1018-30+50M	1238	180	0.10	2.33
MTK0813-16+24M	772	180	0.53	1.50
MTK0828-16+24M	530	180	0.2	1.19
MTK0822-325M	871	180	1.00	1.13
MTK0807-16+24M	516	180	0.33	0.87
MTK0724-16+24M	384	180	0.24	0.23
MTK1016-325M	1239	180	0.92	0.00
MTK1023-325M	870	180	17.87	0.00
MTK0813-325M	772	180	0.41	0.00
Filtrasorb 300-325M	1018	180	0.73	0.00
MTK0729-16+24M	730	180	0.43	0.00
MTK0722-16+24M	451	180	0.35	0.00
MTK0717-16+24M	443	180	0.23	0.00
MTK0715-16_24M	476	180	0.33	0.00

Figure 10.3 Effect of Surface Area on Sulfur Dioxide Adsorption at 25°C



11.0 ENGINEERING ASSESSMENT AND PRELIMINARY COST ESTIMATE

11.1 Design Basis

The design of a combined activated carbon and electric power generating plant to be built at the Mt. Klappan mine site was based on previous studies for a KRW based IGCC system performed by Monenco Consultants in 1988 and the recent IGCC study performed by Bechtel for the Coal Association of Canada (CAC). The plant had a 240 MW equivalent gasification capacity which was the same gas production as CAC design. The 1988 Monenco design was for 450 MW and was deemed too large. In this design concept the steam turbine in the CAC design was eliminated, as steam is required for AC production. Thus, the gas turbine output power is approximately 168 MW.

11.2 Mass and Energy Balances

Fuel energy (coal HHV) input to CAC design, 2173 GJ/hr

From CAC design cold gas efficiency of gasifier was 82%.

Therefore, total gas heating value required to fuel gas turbine is

0.82* 2173 GJ/hr = 1782 G/hr

From previous Gulf contract 1 tonne of Mt.Klappan coal yields:

250 kg Activated Carbon

127 kg Hydrogen

1341 kg Carbon Monoxide

369 kg Carbon Dioxide

Therefore, 1 tonne of coal converted to activated carbon produces:

(127 kgH_2 * 142 MJ/kgH_2) + (1341 kgCO * 10.1 MJ/kgCO) = 31.6 GJ gas HHV

Thus, coal throughput must be:

1782 GJ/hr / 31.6 GJ/tonne = 56 tonne/hr coal feed rate

If the plant will operate 300 days per year (82% availability).

Total Annual Coal Consumption = 300 days/yr * 24 hr/day * 56 tonne/hr = 403,000 tonne/yr

Total Annual Activated Carbon Production = 0.25 * coal feed rate = 100,800 tonne/yr

Total Annual Gross Electric Power Production = 168 MW * 1000 kw/MW * 7200 hr = 1,210,000,000 kWhr

From previous work the water consumption to produce activated carbon by steam activation was 1.09 tonnes of water per tonne of coal, therefore:

Total Annual Water Consumption = 1.09 * 403,000 tonne/yr = 437,560 tonne/yr

(for AC production only)

From Monenco Design make-up water for power plant is 298 litres/second.

The activated carbon production would require:

437,560 tonne/yr * 1000 litre/tonne / 25,920,000 sec/yr = 17 litres/second

Also, from the Monenco Design total cooling water flow in the power plant is 95 m^3/s, or 95,000 litres/second.

Assuming linear scale-up from ARC fluid-bed reactor, total water/steam flowrate for the activated carbon plant was approximately 50 g/min/kg of coal. Required coal feedrate to maintain gas flow required for gas turbine is 56 tonne/hr. Therefore, if we size the activated carbon reactors at 56 tonne of coal batch, 2 hrs. for activation, 1 hr. charge and heat up, 1 hr. discharge and cool-down, 3 reactors are required of which 2 are on steam:

Reactor Steam/Water flow rate = 50 litre/min/tonne / 60 s/min * 56 tonne * 2 = 93 litres/second

Total Steam/Water flow rate = 93 + 17 = 110 litres/second

From CAC design the waste heat recovery system generates about 320 litres/s of 12512 kPa (absolute) of 538°C steam from a total coal feed rate of 3530 tonne/day. The conditions (T and P) at the outlet of the activated carbon gasifier are essentially equal to

the Monenco design and the gases fire a very similar gas turbine. Therefore, it was assumed that the additional heat required to generate the necessary 110 litres/second of steam at 1100°C would come from additional coal firing in the steam generator.

Recoverable waste heat in AC plant:

403,000/1030700 * Recoverable waste heat in Monenco Design

0.3910 * 3300 kJ/kg * 320 kg/s = 413,000 kJ/s

Heat required for AC plant, steam at 1.6 MPa an 1100°C:

110 kg/s * 4890 kJ/kg = 538,000 kJ/s

Additional heat required = 125,000 kJ/s

Coal HHV = 27,490 kJ/kg, assuming 80% boiler efficiency:

125,000 kJ/s / (27,490 kJ/kg * .80) = 6 kg/s * 25,920,000 s/yr =

Additional coal required for steam production = 156,000 tonne/yr

Internal Power Consumption

From CAC design total internal power consumption	37,900 kW
subtract air separation power	24,800 kW
	13,100 kW

Assume equivalent consumption even though coal throughput is much lower, 825,000 tonne/yr in the CAC design vs. 560,000 tonne/yr here. Therefore:

Internal Power Consumption = 13,100 kW * 300 days/yr * 24 hr/day

= 0.094 x 10^9 kWhr

11.3 Preliminary Cost Analysis

Based on cost data from the previous studies the capital, operating and maintenance costs were estimated, see Tables 11.1 and 11.2. Revenues are shown in Table 11.3. Discounted cash flows (DCF's) were also calculated for the combined activated carbon and electric power plant. Two cases were investigated. The first assumed that the product carbon would all be sold for $1000/tonne, the other

$1500/tonne. The assumptions made in the financial analysis were: the plant operated for 300 days/yr over a 20 year life, 100% of the produced carbon and electrical power were sold, plant operating costs (excluding coal) were assumed to be 6% of the capital cost (Monenco study assumed 4%), coal for activated carbon production (low ash) cost $95/tonne, coal for additional heat cost $20/tonne, electric power was sold for $0.035/kW-hr, the depreciation allowance was 35%, taxes at 50%, and zero inflation. Details of the DCF results are given in Appendix III. These calculations show an internal rate of return of 15.2% for the $1000/tonne case and 25.0% for the $1500/tonne case. These economics were very positive considering previous studies have shown an average activated carbon price of $1900/tonne.

Table 11.1 Capital Cost Estimate for Activated Carbon/Power Plant

Item	Description	$ x 10^3 Cdn 4Q92
1	Coal receiving and preparation	35,000
2	Activated carbon handling	7,000
3	Reactors (4 each, scaled from Monenco Design)	25,000
4	Gas clean-up	22,000
5	Gas turbine	40,000
6	Steam generation (2 times CAC design)	40,000
8	Electrical	20,000
9	Auxiliaries	45,000
10	Cooling water and treatment (2 times CAC)	40,000
	DIRECT COST:	**274,000**
11	Indirect costs at 0.3 times capital	82,000
	TOTAL CAPITAL COST:	**356,000**

Table 11.2 Operating Cost Estimate for Activated Carbon/Power Plant

Item	Description	$ x 10^3 Cdn 4Q92
1	O & M costs (6% of capital)	21,360
2	Coal at $20/T for heat, $95/T for AC feed	41,500
	TOTAL OPERATING COST:	**62,860**

Table 11.3 Revenue Estimate for Activated Carbon/Power Plant

Item	Description	$ x 10^3 Cdn 4Q92
1	Power Production	
	(1.21 x 10^9 kWhr - 0.094 x 10^9 kW/hr internal use)	
	- 3.5 cents/kWhr	39,000
2	Activated Carbon Production (100,800 T/Yr)	
	- $1000/tonne	100,800
	- $1500/tonne	151,200

12.0 CONCLUSIONS

1. A literature review of recent technology developments revealed that granular activated carbons (GAC) and carbons impregnated with chemicals receive the greatest attention. The use of chemicals can greatly expand the utilization of activated carbons through mechanisms of chemical sorption or reactions.

2. Fluidized bed is reported to be the most suitable method for activated carbon production from anthracite. It offers uniform treatment of individual particles, good gas-solids contact, and good heat transfer behaviour. This production method was used commercially by Thomas Ness Limited in the U.K. and extensively tested by the Institute of Gas in the USSR.

3. For the activated carbon produced from 30 - 50 mesh Mt. Klappan anthracite surface areas up to 1240 m^2/g were produced at carbon conversion levels of 73 wt%. This surface area was higher than Filtrasorb 300 (1018 m^2/g) and the GRC 22 (1050 m^2/g) commercial carbons.

4. The trends observed in the previous fixed bed unit were confirmed in the fluidized bed system. That is, surface area and pore volume are related to the processing conditions used. As reaction temperatures and residence times increase and particle sizes decrease the surface area and pore volume increases.

5. Characterization of the Mt. Klappan activated carbons in comparison with Calgon's Filtrasorb 300 by Iodine number and Methylene Blue number shows comparable sorption performance for small and large organic molecules. A further characterization using Phenol value, tannin value, and mesitylene value, however, indicates that the Mt. Klappan carbons are less efficient for the removal of polar, ionic or complex structure molecules.

6. Mt. Klappan activated carbons show a greater sorption rate, but a smaller sorption capacity in gold recovery test, than the Calgon GRC-22 product.

7. Sorption capacity for sulfur dioxide based on thermogravimetric analysis indicates that Calgon's Filtrasorb 300 performs slightly better than the Mt. Klappan activated carbons.

8. Different sorption characteristics were observed for the Mt. Klappan activated carbons and activated carbons produced from other sources Filtrasorb (bituminous coal based) and GRC-22 (coconut-based) which presumably are produced under different processing conditions. The different sorption behaviours cannot be satisfactorily explained by surface area data and pore size distribution. Surface chemistry is suspected as a reason for these differences.

9. Discounted cash flows (DCF's) were calculated for a combined activated carbon and electric power plant which produced 101,000 tonnes/yr of activated carbon and 165 MW of electric power. Two cases were investigated: one assumed an activated carbon price of $1000/tonne, the other $1500/tonne. The results of the DCF calculations show an internal rate of return of 15.2% for the $1000/tonne case and 25.0% for the $1500/tonne case. These economics were very positive considering previous studies have shown an average activated carbon price of $1900/tonne.

13.0 RECOMMENDATIONS

There are several recommendations for further research which follow from the work performed so far:

1. The water treatment and solids disposal costs were included in the preliminary cost analysis but they were based on power plant treatment and disposal costs. The properties of the water and solid waste streams should be examined. The waste water may contain impurities, such as hydrogen sulfide, that would have to be removed prior to disposal. Waste water could be recycled to the boiler in an industrial plant, but some treatment of the water might be necessary. The solid waste may be partly activated and would have to be characterized before a disposal option was selected.

2. The high surface area and pore volume obtained in this work demonstrated the potential to manufacture high value activated carbon from Mt. Klappan anthracite. Further studies should be carried out to determine if modified activation techniques or post treatments can enhance performance of the carbon for polar organics absorbtion (phenol and tannin numbers).

3. The trends observed in the previous fixed bed work regarding the relationship between operating conditions (temperature, residence time, and particle size) and results (surface area, pore volume, and pore size distribution) were confirmed in the larger fluidized bed systsem used in this work. However, further work should be considered in the areas of finding a better theoretical model relating surface area to conversion. This would be helpful in predicting the required operating parameters for a specific desired surface area, and might prove useful for further scale up or, in optimizing the process for obtaining the desired surface area and pore size distribution.

4. This study was based on a potentially available coal with an ash content of about 8 wt%. Analyses of present commercial activated carbon, produced from coal, indicate that future work should investigate the possibility of utilizing a lower ash feedstock.

14.0 REFERENCES

The following papers were referred to in the completion of this report:

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3. B. Y. Wong, G. Kovacik, 'Simultaneous Production of Energy and Specialty Products from Low Reactivity Coals', Gulf Canada Resources Ltd., Calgary, 1989

APPENDIX I

LITERATURE REVIEW OF RECENT TECHNOLOGY DEVELOPMENTS IN THE PRODUCTION AND UTILIZATION OF ACTIVATED CARBON

TASK ONE

PRODUCTION OF ENERGY AND SPECIALTY PRODUCTS FOR LOW REACTIVITY COALS

DSS CONTRACT NO. 06.SQ.23440-0-9014

OCTOBER 1991

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SUMMARY

A literature review was conducted in Task 1 of this research contract. The main objectives of this survey are to identify recent technology development in the production and utilization of activated carbon, and use this information to guide the experimental program in this project.

Six data bases were used in this literature review. These include IEA coal data base, Chemical abstracts, Engineering index, Biosis, Enviroline, and NTIS (National Technical Information Services). In addition, a research report on treatment of drinking water by activated carbon was provided by Gulf Canada. The search reveals that recent technology developments in activated carbon concentrate in the utilization technology, for granular activated carbons and carbons impregnated with chemicals.

A review of the influence of process variables show that high activation temperature and longer residence time lead to the production of micropores. However, a shift from micro to meso pores and optimum surface area are observed as carbon burnoff progresses. Alkali additives have been used to enhance reactivity and increase surface area. Activated carbons from anthracites are predominantly microporous in structure because of the nature of the feedstock and the high temperature required for the activation process.

While industrial reactors such as rotary kilns, vertical retorts, and shaft kilns are available, the fluidized bed reactor is most suitable for processing anthracite for the production of activated carbon. The fluidized bed reactor offers uniform treatment of individual particles, good gas-solids contact, and good heat transfer behaviour. A fluidized bed process was developed in the 1960's in the UK for anthracite by the National Coal Board and was subsequently put into commercial operation by Thomas Ness Limited. The same technology has also been extensively tested in a demonstration scale of 200 Kg capacity in the Institute of Gas in USSR. Data showing material consumptions are documented in this literature review. It should be noted that the

fluidized bed reactor was operated in a batch mode to control the residence time of the activation process.

Recent developments in the utilization of activated carbon focused on granular forms and carbons impregnated with chemicals. The use of chemicals can significantly expand the utilization of activated carbon through mechanisms of chemical sorption/reaction, in addition to the physical sorption mechanism available from the large surface areas. All these new applications have been well developed; and commercial installations are already in place. The most important technology developments for the utilization of activated carbon are as follows:

- SO_2 and Nox removal from flue gas
- Purification of landfill gases by pressure swing technique
- Low grade gold recovery
- Treatment of drinking water

Bio-remediation using activated carbon has been well documented in the literature on wastewater treatment. Bacteria adsorbed on activated carbon can partially regenerate the carbon column, making the use of granular activated carbon more cost-effective. The performance of GAC based on combined adsorption and biodegradation was reported to be more stable and reliable. Powdered activated carbon has also been used as a controlling mechanism for the activated sludge process. Most of the studies, however, were conducted in the early 1980's.

The use of a fluidized bed reactor in this project is a good choice of production technology. Activation with alkali additives is suggested as this may reduce the activation temperature and residence time. Assessment of products from this project based on physical sorption mechanism in water treatment and low grade gold recovery should be given top priority. This is because these applications represent the major markets for activated carbon in Western Canada; and the fact that carbons used in recent developments are largely chemically impregnated.

1.0 INTRODUCTION

Activated carbon of surface areas in the range of 1,000 m^2/g was produced from Mt. Klappan anthracite using a laboratory scale fixed bed gasifier in a previous DSS Research Contract, No. 06SQ.23440-8-9033, between CANMET, Gulf Canada and the Alberta Research Council. The current research contract aims at producing kilogram quantities of activated carbon of similar quality, and subsequently evaluates their performance in various applications.

To ensure that recent technology developments in the production and utilization of activated carbon are duly covered in the current project, and to guide the design of the experimental program, a decision was made to first review the recent advancements in both the production and utilization technologies for the activated carbons, with particular emphasis on the activated carbons produced from anthracites. This activity has been organized under Task 1 of the current research contract.

A literature search on these topics was conducted at the Coal Research Centre in Devon. Language of publications was limited to English only and four data bases were used in the literatue survey. In the search of literature on bio-remediation using activated carbon, the data bases of BIOSIS and ENVIROLINE were also used between the period of 1970 to 1991. The data bases used and numbers of articles provided by the key words used in the main search are summarized below:

Data Base	IEA Coal	CA Search*	Eng. Index	NTIS**
Search Period	1978-Jan.91	1987-Jan.91	1970-Dec.90	1964-91
No. of articles	52	16	4	11

* Chemical Abstracts

** National Technical Information Services, US Dept. of Commerce

A preliminary review of these articles was conducted to determine subjects most relevent to the current research contract. This screening was performed by reviewing the abstracts of the publications obtained from the IEA coal data base. As a result of this evaluation, articles considered to be important were requested for detailed study. These articles cover the following areas in the production and utilization of activated carbon.

- Production process fundamentals-process conditions for controlling carbon porosity.
- Industrial reactors for the production of activated carbons.
- Recent developments in the special applications of activated carbons.

Most of these articles were published in the last five years. Emphasis in activated carbon technologies also appears to be on special applications, rather than production. In addition, a report on "Activated Carbon in Drinking Water Technology-AWWA Research Foundation" was provided by Gulf Canada and was reviewed as part of the literature survey. The following sections summarize the results of this literature search.

2.0 INFLUENCE OF PROCESS VARIABLES ON PORE STRUCTURE DEVELOPMENTS IN ACTIVATED CARBON

Information on the effects of process variables on pore structure developments is mainly based on results of laboratory scale experiments conducted on peat semi-coke and brown coal coke. Due to the confidential nature of commercial operation, little data is available on this subject in large scale operations.

General conclusions on the effects of process variables, based on laboratory data of activating peat semi-coke and brown coal coke show the following:

- The pore volume of the activated carbon increases with increasing burnoff. However, an optimum in surface area or micropore volume is observed. This indicates a shift from micro to meso porosity as the burnoff increases at either higher temperature or longer residence time.

- High temperature in activation leads to the formation of micropores. Two mechanisms for pore volume developments are postulated. Pore deepening, which does not affect the pore size, is favored by high temperature activation. Pore drilling, which increases pore diameter, is predominant at low temperature activation.

- Best developed micropore structure is generally expected in steam activation due to its molecular dimension, reactivity, diffusion rate, and the diameters of accessible pores.

- Alkali additives of potassium and sodium compounds are known to enhance reactivity, increase surface area, and promote microporosity.

The effects of activation temperature and residence time are collectively

expressed as carbon burnoff in the literature reviewed. A German anthracite of a volatile content of 6% was used in this study. It was shown that the macropore volume of activated carbon from anthracite decreases as a function of burnoff. The total micro and meso pore volume increases with burnoff. The changes of these pore volumes as a function of carbon burnoff are presented in Figure 1 and 2.

Comments in the articles reviewed in this literature search also concluded that anthracite shows considerable shrinking core behaviour. With the poor accessibility of pores and low reactivity of the anthracite, higher activation temperatures is required. As a result of all these factors, pore structures of activated carbon from anthracites are essentially microporous.

3.0 PRODUCTION TECHNOLOGY OF ACTIVATED CARBON

Very little information was revealed in this literature review on the recent developments of production technology of activated carbon. While the detailed processings in activated carbon production are always guarded carefully by manufacturers, it is also quite possible that little advancements were made in this area in recent years. To guide the design of the experimental program in the current project, the following summarizes the available methods of activation, reactors used, and the operating experience in activated carbon production from anthracite.

3.1 Methods of Activation

Activated carbon can be produced from a variety of carbonaceous materials. These include anthracite, coals, petroleum coke, saw dusts, coconut shells, etc. Activation, the creation of internal pore structures, can be achieved by two basic methods:

- chemical activation
- thermal activation

Figure 4.1 Effect of Carbon Burnoff on Macropore Volume

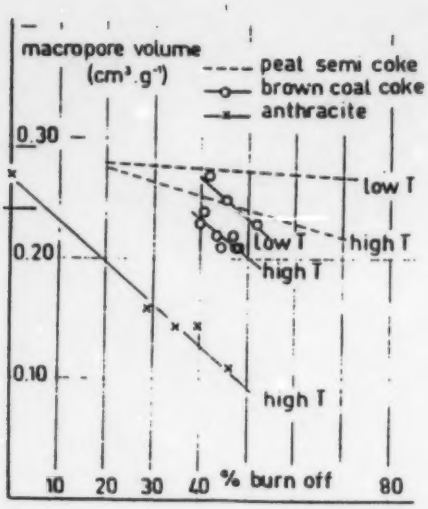
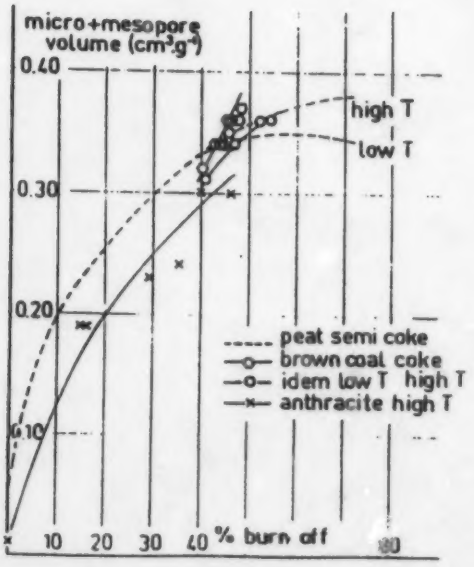


Figure 4.2 Effect of Carbon Burnoff on Micro/Meso Pore Volume



Chemical activation relies on the degradation/oxidation/dehydration of cellulosic structures, and is mainly used for feedstocks with high hydroxyl groups such as saw dusts. It is normally carried out at temperatures above ambient, as high as 600-700°C. Chemical activation utilizes dehydrating/oxidizing agents such as phosphoric acid, sulfuric acid, sodium hydroxide, calcium hydroxide, zinc chloride, etc. Activation of cellulosic feedstocks normally produces large pores at a feedstock/reagent ratio from 0.25 to 2. Chemicals are recovered after the activation process for re-use. This mechanism is not suitable for feedstocks like anthracite which has a predominantly graphite like structure.

Thermal activation process produces the internal pore structure by the removal of volatile components. Feedstocks used in the thermal process range from coconut shells to anthracite. The normal operating temperatures are in the range of 700 - 1000°C, and steam is the most popular activation agent. While the carbonization process used to be carried out separately, increasingly it is carried out together with the activation process in the same reactor. As this is the method most suitable for anthracite activation, discussion of industrial production is therefore limited to thermal activation in this report.

3.2 Industrial Reactors for the Production of Activated Carbon

The thermal activation process is invariably performed in atmospheric equipment. Four different types of industrial reactors can be used for the production of activated carbon:

- Rotary kilns
- Shaft kilns (multiple hearth furnaces)
- Vertical retorts
- Fluidized bed reactors

These industrial reactors provide a wide range of residence time for the carbon in the hot zones of the activation equipment. In addition, there are also differences in the maximum temperature profile in various reactors. Consequently, it is reasonable to expect that the products from different reactors will exhibit different pore structures as a result of the effects of both temperature and residence time.

While four types of industrial reactors are available for the thermal activation of carbonaceous materials, only two processes were developed in the U.K. for the industrial production of the activated carbon. It should be noted that both processes are batch operation. These processes are described in the following sections.

3.2.1 Vertical Retort

The process developed for bituminous coals used a vertical retort as the activation reactor. Bituminous coals are first crushed, and then briquetted before the activation process. This process is not suitable for processing either coking coals, which tend to swell at elevated temperature, or anthracite, which requires higher pressure in briquette formation.

Figure 3 shows the basic components in a vertical retort. The retort is typically 4 meters in length. The residence time in the reactor is controlled by the rocking plate at the bottom. It was reported that this type of reactor has a high efficiency in fuel utilization.

3.2.2 Fluidized Bed Reactor

The fluidized bed reactor was used for anthracite activation after many unsuccessful attempts in the conventional kilns. A process was developed by the National Coal Board (NCB) in the 1960's and put into commercial operation by Thomas Ness Limited. A flow diagram of the NCB process is presented in Figure 4.

Figure 4.3 Vertical Retort for Activated Carbon from Bituminous Coals

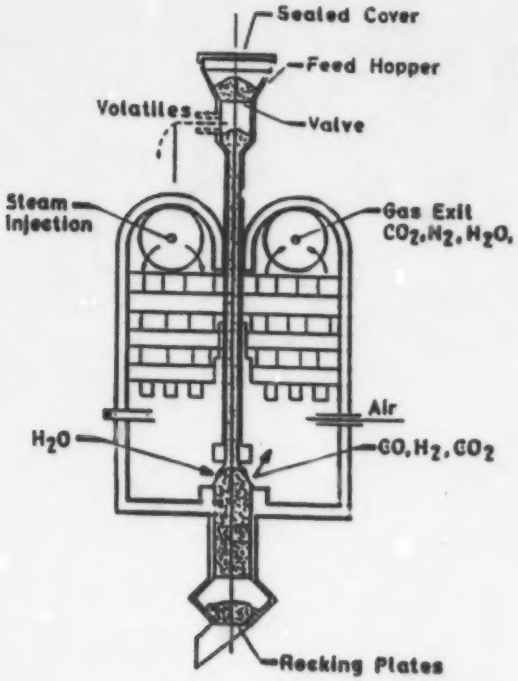
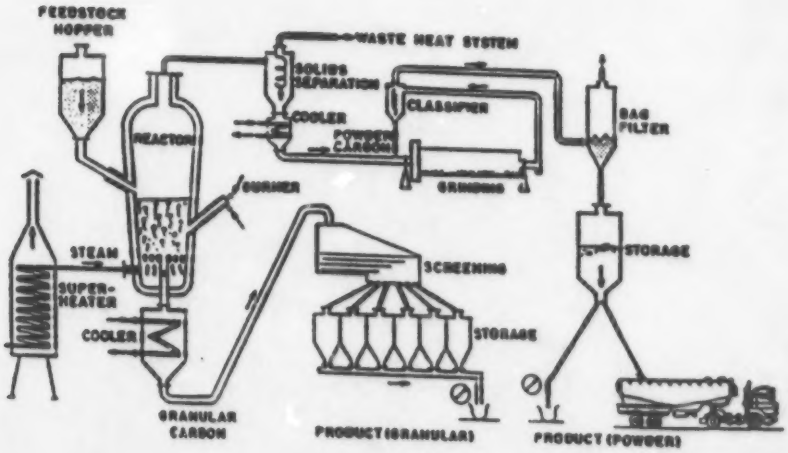


Figure 4.4 Fluidized Bed Reactor for Activated Carbon from Anthracite



A fluidized bed reactor was chosen for anthracite because uniform treatment of individual particles, good gas-solids contact, and good heat transfer can be achieved in the reactor. It is particularly suitable for anthracite because of its intrinsic hardness which gives higher resistance to particle attrition during fluidization. The process also eliminated the need of reconstituting crushed materials. The NCB process was operated in a batch mode which offered good control of residence time. Fluidizing velocity of the steam in the range of 1.0 m/sec. was used in industrial operation. Combustion gases were not recovered but were utilized for heat generation in specially designed burners immersed in the reactor.

In addition, the use of classification devices in the NCB process allows a rough separation of the granular and powdered activated carbons. These products were further graded and cooled before product packaging. The Thomas Ness plant was only recently closed.

3.2.3 Kilns

Although it was mentioned that industrial scale rotary kilns have the advantage of only small discharges of inert gas, little information on the utilization of the rotary kilns for the production of activated carbon was obtained in this literature review. Laboratory scale kilns were used for activation experiments on high-temperature lignite coke (1000°C, Bilkenroth-Rammler Process) as well as on low-temperature lignite coke (600°C, Lurgi Process). Rotary kilns were used in chemical activation when the operating temperatures are generally lower.

3.3 Operating Experience of Fluidized Bed Reactor for Anthracite Activation

The technology of steam activation of anthracite in fluidized bed reactor was extensively studied in the Institute of gas in USSR. Donetsk anthracite (moisture 5%, ash

7-8%, volatile matter 6-7%) was used as feedstocks in the laboratory scale, pilot scale, and demonstration scale processing 200 gm, 50 Kg and 180 Kg respectively in a batch mode operation. The demonstration unit was operated for four years.

It has been reported that by using a gas distributor of 1 m^2 area, 0.5-1.6 TPD of activated carbon can be produced from the demonstration unit with a chamber height of 800 mm. It has also been reported that to produce one tonne of activated carbon, 3 tonnes of anthracite, 10 tonnes of steam, 1,600 m3 of natural gas, and 960 Kw-hr of electrical energy were required. The demonstration unit was operated at 1000°C and a gas velocity between 0.75-0.95 m/sec.

Little information was provided for activation of anthracite on the industrial scale to produce up to 5 tonnes of anthracite. However, it was mentioned that about the same yield of activated carbon was achieved and only 1,100 m3 of natural gas and 6 tonnes of steam were required for each tonne of activated carbon.

4.0 UTILIZATION TECHNOLOGY OF ACTIVATED CARBON

Physical adsorption is the main mechanism in the utilization of activated carbon. The applicability of activated carbon is determined by both the adsorption capacity, and the rate of adsorption. These two factors are inherent in the pore structure of the activated carbon. The adsorption capacity is related to the degree of activation and the molecular dimensions of the adsorbates. The rate of adsorption is governed by the molecular dimensions and the medium from which the adsorption occurs.

However, it should be noted that by impregnating chemicals onto activated carbon, chemical sorption becomes possible. Impregnated activated carbons have found applications in the nuclear industry, mercury removal, NH_3 removal in landfill gas purification, etc. The scope of activated carbon utilization can be significantly broadened by impregnating chemicals onto activated carbons.

The powdered and granular forms of activated carbon differ considerably in usage. Powdered activated carbon (PAC) is almost entirely used in liquid phase applications and is normally disposed of after applications. Granular carbons (GAC) can be used in both liquid and gas phase applications, and they are usually regenerated by thermal oxidation. The superior performance of GAC in the removals of toxic chemicals in drinking water by filtration process may further depress the markets for PAC in the future.

4.1 Conventional Applications of Activated Carbons

Activated carbons are utilized in either liquid or gas phase applications. Conventional applications of activated carbons include sugar decolorization, food and beverage processings, waste water treatment for the reduction of biological and chemical oxygen demands (BOD and COD), removals of taste and odor, treatment of industrial effluents from paper pulp mills, phenol removals from refineries, chemical plants, and coking plants, solvent recovery, separation of nitrogen from air, ozone removal, etc. These applications are technically proven by using either GAC or PAC.

4.2 New Applications of Activated Carbons

While certain areas of the conventional applications for activated carbon are declining (such as sugar decolorization), the applications of activated carbon in gold recovery, flue gas treatment, purification of landfill gas, treatment of potable water, etc. are increasing. Recent technology developments also favor the use of granular activated carbon and chemical impregnations. New technology developments in these applications are described below.

4.2.1 SO_2 and NOx Removal from Flue Gas

This technology was developed by Bergbau-Forschung GmbH in Germany

to meet SO_2 and NOx emission regulations (400 mg/m^3 and 200 mg/m^3 respectively for electrical capacity above 300 MW). The operating temperatures of the adsorption process are between 80 to 150°C, hence, no cooling or reheating of flue gas are required in this application. It has been reported that 98% of the SO_2 is removed; and NOx emission is reduced by 80%. The process produces no waste water but sulfuric acid, which can be used as a chemical feestock. The spent carbons are regenerated by thermal treatment. A flow diagram for this process is presented in Figure 5.

The principles of operation of this process are:

- SO_2 adsorbed on activated carbon is converted to sulfuric acid by reacting with oxygen and steam,
- NO is reduced catalytically by activated carbon to nitrogen in the presence of ammonia.

In 1986, a commercial plant treating 30,000 m^3/h of flue gas was operated by Mitsui Mining Corporation Ltd. in Omuta, Japan. Another commercial plant (1.1 million m^3/h flue gas from a 237 MW lignite power plant) was recently constructed by Uhde GmbH in Bavaria.

4.2.2 Natural Gas from Landfill Gases

This technology which involves a pressure-swing (pressure changing) operation was developed by Bergbau Forschung GmbH in Germany to clean up landfill gas to meet natural gas quality. Impurities such as H_2S, NH_3, Hg, halogenated hydrocarbons, higher alkalenes, aromatics are removed by activated carbon. CO_2 and methane are then separated by changing the pressure on a carbon molecular sieve (CMSC). A flow diagram of this process is presented in Figure 6.

The principles of operation of this process are:

Figure 4.5 Flow Diagram of the Bergbau-Forschung Process for SO_2 and Nox Removal

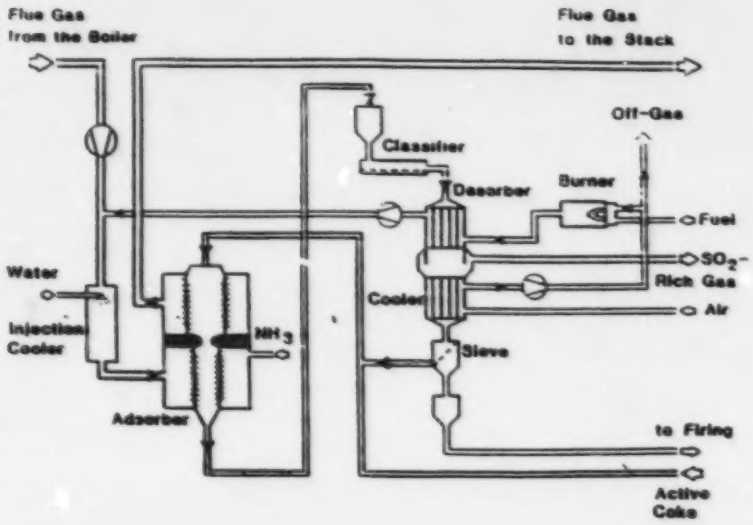


Figure 4.6 Flow Diagram of the Pressure Swing Process for Purification of Landfill Gas to Natural Gas Quality

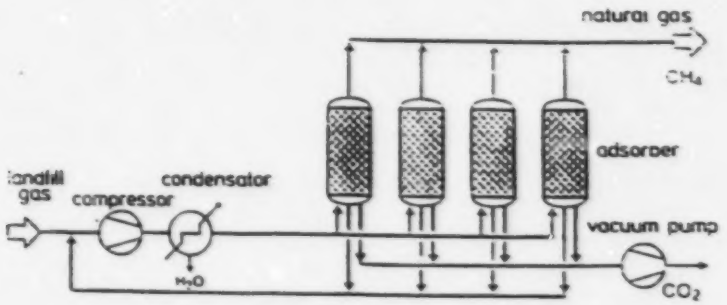
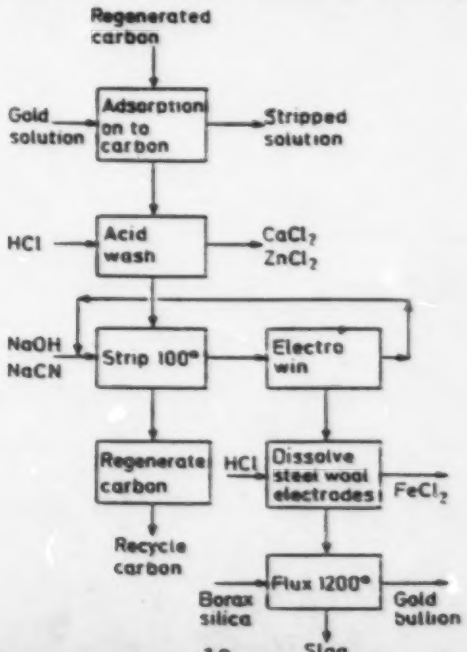


Figure 4.7 Flow Diagram of the CIP (Carbon-In-Pulp) Process for Low-Grade



- H_2S is converted to elemental sulfur by catalytic oxidation on activated carbon.
- NH_3 is converted to $(NH_4)2S04$ using activated carbon impregnated with sulfuric acid.
- Hg is removed as HgS using activated carbon impregnated with sulfur.

- Halogenated hydrocarbons are removed by physical adsorption on activated carbon.
- CO_2 is removed by carbon molecular sieve by pressure swing technique. The CMSC used in this process was produced by Bergwerksverband GmbH.

In 1987, a pilot plant of 1 m^3/h capacity was in existence at the central landfill site of Emscherbruch Gelsenkirchen FRG and a demonstration plant (30 m^3/h) are under consideration at various dutch landfill sites and water treatment plants.

4.2.3 Low Grade Gold Recovery

The development of the Carbon-in-pulp (CIP) process has enabled gold to be recovered economically from low-grade gold deposits. Activated carbon is mixed with ground ore/water slurry containing gold cyanide. Gold is adsorbed onto the carbon which is mechanically separated from the pulp or slurry. Activated carbons are regenerated and gold is recovered by electrowinning.

4.2.4 Treatment of Drinking Water

The main objectives of treatment of drinking water are to remove organic contaminants which give toxicity and mutagenity, in addition to the removal of compounds which impart taste and odor. Extensive studies have been carried out in this area, and a report entitled "Activated Carbon in Drinking Water Technology" from the AWWA Research Foundation was provided by Gulf Canada for this literature review. This report

summarizes the research efforts and operating experiences of using activated carbon in the Netherlands Waterworks testing and Research Institute during the period of 1971 to 1981.

The major conclusions of the research and operating experiences are:

- granular activated carbon was found more effective in the removal of organic compounds which are hygienically undesirable in drinking water,
- the use of granular activated carbon, instead of powdered activated carbons, necessitates the change in process sequences in drinking water treatment. While PAC was commonly applied before coagulation and/or filtration, the CC contactor was generally applied at the end of the process.

The research and testing at the Netherlands Waterworks also investigated new processes developed for the powdered forms of activated carbons. Instead of applying the powdered activated carbons in a mixing basin as used in the conventional manner, adherence of PAC to a carrier material to allow the combined materials as a filtration medium was tested in the Haberer Process. In addition, powdered activated carbons were flocculated by a polyelectrolyte to form larger agglomerates and used in a fluidized bed. It was found that the process using flocculated PAC did not warrant further pilot scale evaluation.

During the developments of applying activated carbons for the treatment of drinking water, extensive research efforts were spent in defining product specifications and analytical methods for the organic contaminants. It was concluded in the report that both areas require continuing development. Carbon selection in drinking water treatment was carried out mainly on the basis of pilot plant tests. In analytical developments, synthetic solutions consisting of trichloroethyl, phosphate, p-nitrophenol, and tetrapropyl benzene sulfonate were used but both analytical techniques, interferences, and concentration levels give problems in analytical accuracy. In many cases, UV-extinction

and TOC were used as testing parameters.

The work conducted by the Netherlands Waterworks showed that trichlorethylene (TCE) can be removed very efficiently, but trihalomethanes can be removed with only moderate success. It was also reported that phosphated pesticides were moderatedly removed, while the removal of toluene, ethylbenzene, xylenes were excellent.

This report is a very specialized summary of research and operating experience in drinking water treatment. A detailed evaluation is beyond the scope of this literature review. It should, however, be noted that during the period of 1971 to 1981 seven carbon filters were installed in the Netherlands, and two more waterworks started to utilize carbon filters between 1982 to 1984.

4.2.5 Bio-Remediation Using Activated Carbon

Activated carbons have been shown to be a preferred medium for the colonization of bacteria, due to their high surface areas, rough surface textures, and the ability to adsorb organic materials. Furthermore, bacteria attached to activated carbons can utilize adsorbed organic materials as growth substances. The combined effect gives large bacteria population and promotes partial regeneration of the carbon bed, referred to as "bioregeneration" of the activated carbon. The overall rate of bacteria growth has been investigated on granular activated carbon contactors at the Philadelphia Torresdate Water Treatment Pilot Plant facility, and the majority of the bacteria were classified as the genus pseudomonas and the flavo-bacterium cytophaga groups when domestic wastewater from the treatment plant in Dundas, Ontario was tested in activated carbon contactors.

Results from pilot plant studies showed that biological activity on activated carbon gave higher carbon column loadings than those obtainable from non-biological

adsorption. Thus, biological processes can enhance the cost effectiveness of carbon applications, and physical, chemical and biological mechanisms are all involved in the utilization of activated carbon contactors.

Comparison made between a granular activated carbon column with microbial activity and column with only bacteria loading, for the removal of chlorinated organic compounds at Stanford University showed that the combination of biodegradation and adsorption gave both stability and reliability to the GAC performance. Biological mechanism in the GAC column was confirmed by carbon-14 tracer experiments. Higher removal efficiency for chlorinated compounds was obtained under varying conditions of organic compound concentrations, oxygen availability, and varying absorption capacity of the GAC.

Improvement of the activated sludge treatment process, which consists of an aerobic biological reactor and solid/liquid separator, was observed by adding powdered activated carbon in wastewater treatment for the removal of phenols. The addition of PAC to the activated sludge process greatly reduced the concentrations of the phenols in the effluent and permitted operation with "Shock loading" in phenol concentrations in the influents. Addition of powdered activated carbon has been suggested as a controlling mechanism for the operation of the activated sludge treatment process.

It should, however, be noted that bacteria growth in activated carbon column can also have potential detrimental consequences. The increase of bacteria in the column effluents can adversely affect downstream uses of the treated water. Shear forces induced by the flow rate, the roughness of the activated carbon texture, and the surface area have all been reported as controlling factors in the growth of bacteria.

5.0 CONCLUSIONS AND RECOMMENDATIONS

5.1 Conclusions of Literature Survey

The following major conclusions can be made from this literature review:

- Activated carbon from anthracite are mainly microporous in pore structure.
- Fluidized bed reactors were used in the commercial production of activated carbon from anthracite by Thomas Ness Limited. The technology was also extensively tested in the USSR.
- Utilization of activated carbon will favor granular forms over the powdered form in new applications such as flue gas cleaning, purification of landfill gas, low grade gold recovery, and treatment of drinking water.
- Chemical impregnation can significantly expand the applications of activated carbon. Both physical sorption and chemical sorption/reaction become available mechanisms in the utilization of activated carbon.

5.2 Recommendations for Experimental Program

The use of the fluidized bed reactor in the current project is a good choice of activation technology. While it will be difficult to alter the pore structures of the activated carbon from anthracite, it may be worthwhile to investigate the effect of alkali additives. Alkali additions may enhance the reactivity of the anthracites, hence, lower the operating temperature or shorten the residence time in the production of activated carbon. This in turn may produce a somehwat different ratio of meso to micro pores.

A detailed characterization of the activated carbon produced in this project may prove to be difficult. This is partly due to the fact that many carbons used in the recent developments are chemically impregnated; and partly due to the lack of laboratory capabilities in these applications. In order to obtain a fair assessment of the products

from the current contract, utilization based on physical sorption should be emphasized. Conventional water treatment for the removal of odor/taste, and low grade gold recovery should be given priority in the experimental program. These applications are also consistent with the current market demands in western Canada.

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APPENDIX II

ARC - COAL AND HYDROCARBON PROCESSING DEPT.(SURFACE LABORATORY)

DIGISORB 2600 V3.03
105

TK-0530 CHAR
TION 2 STARTED 8/15/91 14:50

NITROGEN

PRESSURE (MMHG)	VOL ADSORBED (CC STP/G)	ELAPSED TIME (HR:MN)	SATURATION PRESS (MMHG)	BET SURFACE AREA ESTIMATE (M2/G)
		0: 0	714.515	
35.385	0.0490	0: 6		
49.939	0.0588	0:10		
64.086	0.0736	0:14		
78.669	0.0799	0:19		
92.826	0.0881	0:23		
		0:26	713.064	
107.321	0.0963	0:31		
121.215	0.1100	0:36		
135.430	0.1242	0:40		
149.785	0.1288	0:44		0.666
178.182	0.1475	0:48		
213.763	0.1660	0:52		
283.830	0.2155	0:57		
		0:59	713.362	
355.366	0.2705	1: 3		
391.739	0.2854	1: 7		
426.536	0.3176	1:11		
445.187	0.3528	1:15		
464.018	0.3627	1:19		
497.714	0.3953	1:23		
516.284	0.4389	1:28		
535.318	0.4453	1:32		
		1:36	713.990	
568.907	0.4785	1:39		
642.250	0.6273	1:47		
677.887	0.7554	1:52		
		1:55	713.587	
709.573	1.3364	2: 2		
		2: 4	713.842	

TK-0530 NITROGEN
ION 2 STARTED 8/15/91 14:50 COMPLETED 8/16/91 1:36

ISOTHERM PLOT

% OF MAXIMUM VOLUME VERSUS RELATIVE PRESSURE

MAX VOL SORBED = 1.3364 CC/G STP MAX VOL FOR PLOT = 1.3364 CC/G STP

1TK-0530
STATION 2 STARTED 8/15/91 14:50 COMPLETED 8/16/91 1:36 NITROGEN

ADSORPTION ISOTHERM

SAMPLE WEIGHT: 2.0493 G
FREE SPACE: 81.9156 CC
EQUILIBRATION INTERVAL: 10 SECS
MAX VOL INCREMENT: 50.000 CC/G STP

P/PO	VOL ADSORBED (CC/G AT STP)
0.04957	0.04903
0.06998	0.05880
0.08982	0.07363
0.1103	0.07987
0.1302	0.08810
0.1505	0.09634
0.1700	0.1100
0.1899	0.1242
0.2100	0.1288
0.2498	0.1475
0.2997	0.1660
0.3979	0.2155
0.4981	0.2705
0.5490	0.2854
0.5978	0.3176
0.6238	0.3528
0.6501	0.3627
0.6973	0.3953
0.7232	0.4389
0.7498	0.4453
0.7969	0.4785
0.8998	0.6273
0.9499	0.7554
0.9941	1.3364

TX-0530 NITROGEN
STATION 2 STARTED 8/15/91 14:50 COMPLETED 8/16/91 1:36

SPECIFIC SURFACE AREA

BET SURFACE AREA:	0.6659	+/-	0.0683 SQ M/G
SLOPE:	5.632866	+/-	0.664239
INTERCEPT:	0.904061	+/-	0.090404
C:	7.2306		
VM:	0.1530 CC		
CORRELATION COEFFICIENT	0.9669		

RELATIVE PRESSURE RANGE: 0.0500 TO 0.2100

TK-0530
TION 2 STARTED 8/15/91 14:50 COMPLETED 8/16/91 1:36 NITROGEN

ADSORPTION PORE VOLUME AND PORE AREA DISTRIBUTIONS

PORE DIA. RANGE, A	AVERAGE DIA.,A	PORE VOLUME (CC/G)	CUMULATIVE PORE VOLUME	PORE AREA (SQ M/G)	CUMULATIVE PORE AREA
3269.4- 396.5	433.8	0.000868	0.000868	0.080	0.080
396.5- 206.2	242.7	0.000205	0.001073	0.034	0.114
206.2- 102.6	119.8	0.000256	0.001328	0.085	0.199
102.6- 79.1	85.9	0.000050	0.001379	0.023	0.223
79.1- 70.2	73.5	0.000004	0.001382	0.002	0.224
70.2- 63.6	66.2	0.000086	0.001468	0.052	0.276
63.6- 54.4	57.9	0.000054	0.001522	0.038	0.314
54.4- 49.5	51.3	0.000012	0.001534	0.009	0.323
49.5- 45.7	47.2	0.000071	0.001605	0.060	0.383
45.7- 40.0	42.2	0.000055	0.001660	0.052	0.435
40.0- 34.8	36.7	0.000014	0.001674	0.015	0.451
34.8- 27.4	29.8	0.000094	0.001768	0.126	0.576
27.4- 21.3	23.1	0.000078	0.001846	0.135	0.711
21.3- 18.2	19.1	0.000019	0.001865	0.041	0.752
18.2- 16.2	16.8	0.000024	0.001889	0.057	0.809
16.2- 14.1	14.4	0.000023	0.001912	0.064	0.873
14.1- 13.2	13.5	0.000021	0.001933	0.061	0.934
13.2- 12.2	12.6	0.000004	0.001937	0.014	0.947
12.2- 11.3	11.6	0.000003	0.001941	0.012	0.959
11.3- 9.4	9.7	0.000016	0.001956	0.065	1.024

LIQUID EQUIVALENT OF MAXIMUM VOLUME SORBED: 0.002067 CC/G

TK-0530 NITROGEN
TATION 2 STARTED 8/15/91 14:50 COMPLETED 8/16/91 1:36

INCREMENTAL PORE VOLUME DISTRIBUTION (ADSORPTION)

% OF MAXIMUM PORE VOLUME VERSUS AVERAGE PORE DIAMETER, ANGSTROMS
MAX INC PORE VOLUME = 0.000868 CC/G MAX INC FOR PLOT = 0.000868 CC/G

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                20%          40%          60%          80%         100%
    I'''''''''''''I''''''''''''I''''''''''''I''''''''''''I''''''''''''I
  3.5
  4.4
  5.5
  6.8
  8.5
 10.6
 13.2 *
 16.5
 20.5 ***
 25.6 ******
 31.9 *****
 39.7 ***
 49.5 ***
 61.6 *****
 76.8 *
 95.7 *********
119.2 ********************
148.5 ********************
185.0 ******************
230.5 ******************
287.1 ********************************
357.7 ****************************************************
445.6
555.2
691.7
861.7
1073.5
1337.4
1666.1
2075.7
2585.9
3221.5
4013.4
5000.0
```

X-0530 NITROGEN
TION 2 STARTED 8/15/91 4:30 COMPLETED 8/16/91 1:36

INCREMENTAL PORE AREA DISTRIBUTION (ADSORPTION)

% OF MAXIMUM PORE AREA VERSUS AVERAGE PORE DIAMETER, ANGSTROMS
AX INC PORE AREA = 0.135 SQ M/G MAX INC FOR PLOT = 0.135 SQ M/G

```
                20%          40%          60%          80%          100%
    I'''''''''''I''''''''''''I''''''''''''I''''''''''''I''''''''''''I
 3.5
 4.4
 5.5
 6.8
 8.5
10.6
13.2 ************************
16.5
20.5 ****************************************
25.6 ************************************************************************
31.9 ********************************************
39.7 ******************
49.5 ***************
61.6 **********************
76.8 ****
95.7 **********************
119.2 *****************************************
148.5 ************************************
185.0 ****************************
230.5 ******************
287.1 ************************
357.7 *********************************
445.6
555.2
691.7
861.7
1073.5
1337.4
1666.1
2075.7
2585.9
3221.5
4013.4
5000.0
```

ARC - COAL AND HYDROCARBON PROCESSING DEPT.(SURFACE LABORATORY)

DIGISORB 2600 V3.03 PAGE 1
105

[illegible]-0715 NITROGEN
[illegible]TION 1 STARTED 8/ 6/91 14:26

PRESSURE (MMHG)	VOL ADSORBED (CC STP/G)	ELAPSED TIME (HR:MN)	SATURATION PRESS (MMHG)	BET SURFACE AREA ESTIMATE (M2/G)
		0: 0	721.714	
0.096	49.2341	0: 9		
15.831	96.7118	0:34		
		0:36	722.235	
35.823	106.8600	0:51		
50.216	112.1351	1: 7		
		1: 9	721.589	
65.255	116.8099	1:20		
79.600	120.6757	1:27		
94.430	124.2285	1:35		
109.263	127.4483	1:42		
		1:44	720.358	
123.950	130.4595	1:52		
138.859	133.2362	1:59		
154.136	135.8186	2: 5		476.179
180.414	139.7200	2:12		
218.566	144.3465	2:19		
		2:21	720.249	
289.739	150.1516	2:29		
359.095	152.9802	2:35		
393.421	153.8447	2:40		
429.924	154.8535	2:45		
450.039	155.2178	2:49		
467.292	155.6075	2:53		
		2:57	719.844	
502.555	156.4123	3: 0		
521.288	156.8243	3: 5		
539.349	157.1409	3: 9		
573.852	158.0405	3:15		
647.335	159.5452	3:23		
684.202	160.4969	3:28		
		3:31	718.956	
715.380	162.3277	3:36		
		3:39	719.758	

TK-0715 NITROGEN
TATION 1 STARTED 8/ 6/91 14:26 COMPLETED 8/ 6/91 21: 7

ISOTHERM PLOT

% OF MAXIMUM VOLUME VERSUS RELATIVE PRESSURE
AX VOL SORBED = 162.3277 CC/G STP MAX VOL FOR PLOT = 162.3277 CC/G STP

TK-0715 NITROGEN
TATION 1 STARTED 8/ 6/91 14:26 COMPLETED 8/ 6/91 21: 7

ADSORPTION ISOTHERM

AMPLE WEIGHT: 0.2797 G EQUILIBRATION INTERVAL: 10 SECS
REE SPACE: 87.8388 CC MAX VOL INCREMENT: 50.000 CC/G STP

P/PO	VOL ADSORBED (CC/G AT STP)
0.000133	49.234
0.02192	96.712
0.04962	106.86
0.06959	112.14
0.09048	116.81
0.1104	120.68
0.1310	124.23
0.1517	127.45
0.1721	130.46
0.1928	133.24
0.2140	135.82
0.2505	139.72
0.3035	144.35
0.4023	150.15
0.4987	152.98
0.5464	153.84
0.5971	154.85
0.6251	155.22
0.6491	155.61
0.6982	156.41
0.7244	156.82
0.7496	157.14
0.7977	158.04
0.9001	159.55
0.9516	160.50
0.9942	162.33

ITK-0715 NITROGEN
STATION 1 STARTED 8/ 6/91 14:26 COMPLETED 8/ 6/91 21: 7

SPECIFIC SURFACE AREA

BET SURFACE AREA:	476.1120	+/-	3.2189 SQ M/G
SLOPE:	0.009118	+/-	0.000061
INTERCEPT:	0.000026	+/-	0.000008
C:	357.6601		
VM:	109.3706 CC		
CORRELATION COEFFICIENT	0.9999		

RELATIVE PRESSURE RANGE: 0.0500 TO 0.2100

TK-0715 NITROGEN
TION 1 STARTED 8/ 6/91 14:26 COMPLETED 8/ 6/91 21: 7

ADSORPTION PORE VOLUME AND PORE AREA DISTRIBUTIONS

PORE DIA. RANGE, A	AVERAGE DIA.,A	PORE VOLUME (CC/G)	CUMULATIVE PORE VOLUME	PORE AREA (SQ M/G)	CUMULATIVE PORE AREA
3373.3- 412.8	451.7	0.002777	0.002777	0.246	0.246
412.8- 210.1	247.1	0.001692	0.004469	0.274	0.520
210.1- 106.0	123.3	0.002953	0.007422	0.958	1.478
106.0- 82.1	89.0	0.001864	0.009286	0.838	2.316
82.1- 73.5	76.6	0.000630	0.009916	0.329	2.645
73.5- 66.8	69.5	0.000866	0.010782	0.498	3.143
66.8- 57.2	60.9	0.001749	0.012531	1.150	4.293
57.2- 52.6	54.3	0.000853	0.013383	0.629	4.921
52.6- 48.6	50.2	0.000774	0.014157	0.616	5.537
48.6- 42.7	45.0	0.002370	0.016527	2.108	7.645
42.7- 37.8	39.6	0.002018	0.018545	2.041	9.686
37.8- 30.7	33.0	0.007370	0.025916	8.924	18.611
30.7- 24.5	26.4	0.016648	0.042564	25.268	43.878
24.5- 21.2	22.2	0.013566	0.056130	24.459	68.338
21.2- 19.3	19.9	0.011488	0.067617	23.080	91.417
19.3- 18.1	18.5	0.007571	0.075189	16.387	107.805
18.1- 17.1	17.5	0.008141	0.083330	18.619	126.423
17.1- 16.2	16.5	0.008797	0.092127	21.291	147.714
16.2- 15.2	15.6	0.009205	0.101333	23.648	171.361
15.2- 14.3	14.6	0.010006	0.111338	27.414	198.775
14.3- 13.3	13.6	0.010680	0.122019	31.364	230.139
13.3- 12.2	12.6	0.012560	0.134579	39.879	270.018
12.2- 11.1	11.5	0.013353	0.147933	46.484	316.502
11.1- 9.4	10.0	0.023123	0.171055	92.898	409.400
9.4- 5.9	6.4	0.102045	0.273100	639.803	1049.203

LIQUID EQUIVALENT OF MAXIMUM VOLUME SORBED: 0.251089 CC/G

TK-0715 NITROGEN
TION 1 STARTED 8/ 6/91 14:26 COMPLETED 8/ 6/91 21: 7

INCREMENTAL PORE VOLUME DISTRIBUTION (ADSORPTION)

% OF MAXIMUM PORE VOLUME VERSUS AVERAGE PORE DIAMETER, ANGSTROMS
MAX INC PORE VOLUME = 0.102045 CC/G MAX INC FOR PLOT = 0.102045 CC/G

```
              20%          40%          60%          80%          100%
    I'''''''''''I''''''''''''I''''''''''''I''''''''''''I''''''''''''I
  3.5
  4.4
  5.5
  6.8 ************************************************************
  8.5 ********************************
 10.6 ************
 13.2 *******
 16.5 ******
 20.5 ********
 25.6 **********
 31.9 ******
 39.7 *
 49.5 *
 61.6 *
 76.8
 95.7 *
119.2 **
148.5 **
185.0 *
230.5 *
287.1 *
357.7 **
445.6 **
555.2
691.7
861.7
1073.5
1337.4
1666.1
2075.7
2585.9
3221.5
4013.4
5000.0
```

TK-0715 NITROGEN
STATION 1 STARTED 8/ 6/91 14:26 COMPLETED 8/ 6/91 21: 7

INCREMENTAL PORE AREA DISTRIBUTION (ADSORPTION)

% OF MAXIMUM PORE AREA VERSUS AVERAGE PORE DIAMETER, ANGSTROMS
MAX INC PORE AREA = 639.803 SQ M/G MAX INC FOR PLOT = 639.803 SQ M/G

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                20%          40%          60%          80%          100%
    I'''''''''''''I''''''''''''I''''''''''''I''''''''''''I''''''''''''I
  [illegible].5
  [illegible].4
   5.5
  [illegible].8 ************************************************************
  [illegible].5 ******************************
  10.6 *******
  13.2 ****
  [illegible].5 **
  [illegible].5 **
  25.6 ***
  [illegible].9 *
  [illegible].7
  49.5
  [illegible].6
  [illegible].8
  95.7
 119.2
 1[illegible]3.5
 1[illegible]5.0
 230.5
 2[illegible]7.1
 3[illegible]7.7
 445.6
 5[illegible]5.2
 6[illegible]1.7
 861.7
1073.5
1[illegible]7.4
1[illegible]6.1
2075.7
2[illegible]5.9
3[illegible]1.5
4013.4
5000.0
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ARC - COAL AND HYDROCARBON PROCESSING DEPT.(SURFACE LABORATORY)

DIGISORB 2600 V3.03
105

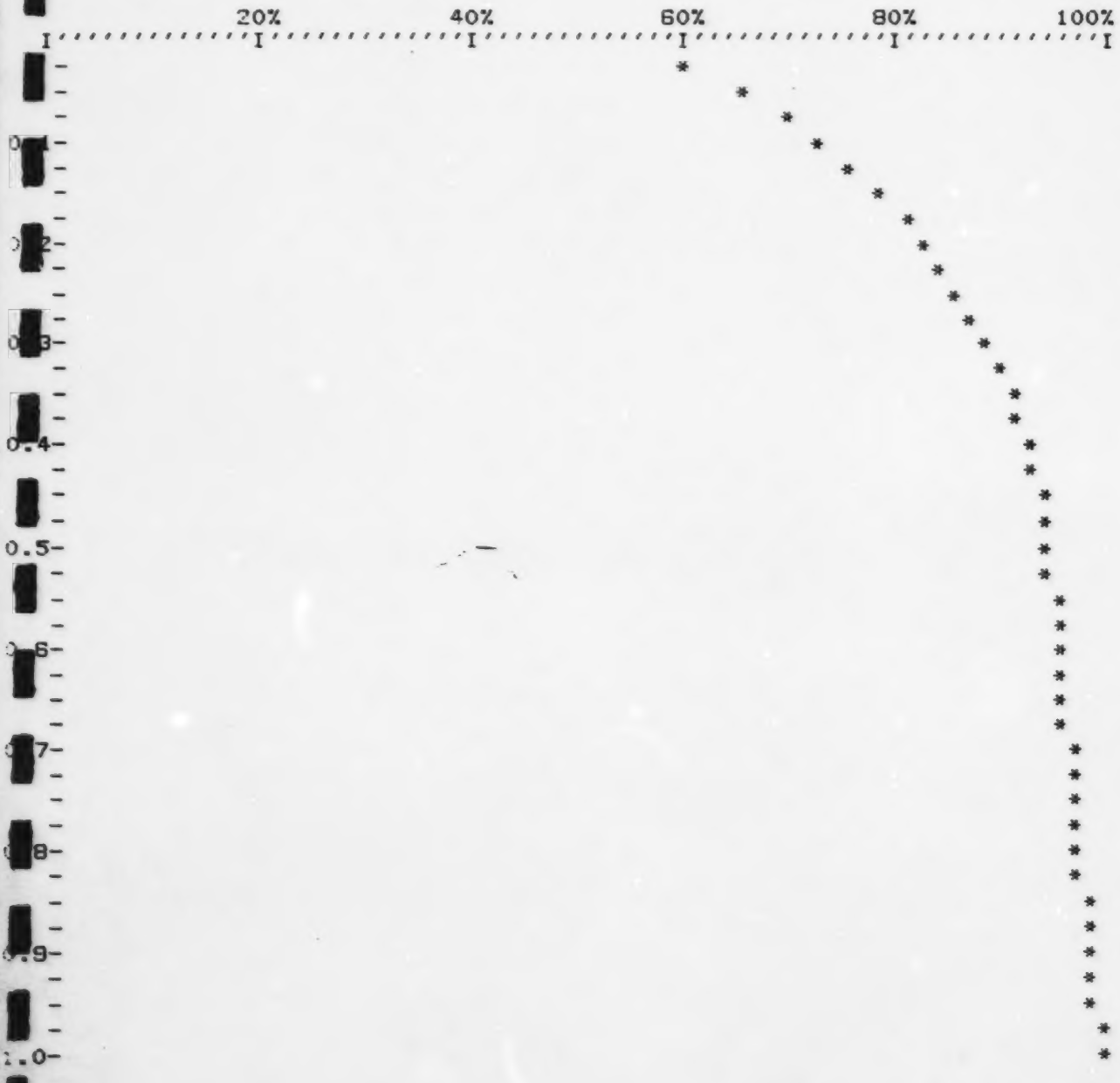
TK-0717 NITROGEN
STATION 2 STARTED 8/ 6/91 14:26

PRESSURE (MMHG)	VOL ADSORBED (CC STP/G)	ELAPSED TIME (HR:MN)	SATURATION PRESS (MMHG)	BET SURFACE AREA ESTIMATE (M2/G)
		0: 0	719.758	
0.078	45.6247	0:26		
		0:29	719.113	
21.606	93.2448	0:53		
35.567	99.3849	1:10		
		1:14	718.735	
49.411	104.1377	1:27		
67.726	109.3345	1:36		
79.273	112.2500	1:46		
		1:49	718.315	
93.930	115.6010	1:59		
108.832	118.6007	2: 7		
123.645	121.4321	2:15		
138.786	124.0587	2:23		
		2:25	717.583	
154.137	126.4743	2:33		443.035
180.296	130.0916	2:42		
217.969	134.4113	2:50		
289.286	139.8566	2:58		
		3: 2	716.799	
357.523	142.5776	3: 8		
394.277	143.6094	3:16		
430.147	144.3264	3:21		
447.289	144.6331	3:25		
465.189	144.9922	3:29		
500.128	145.6938	3:33		
		3:35	716.017	
518.936	146.1210	3:39		
536.959	146.4250	3:43		
571.360	147.0135	3:47		
644.098	148.5257	3:56		
680.517	149.4292	4: 0		
		4: 3	716.358	
711.522	150.8454	4: 8		
		4:10	716.407	

TK-0717 NITROGEN
TION 2 STARTED 8/ 6/91 14:26 COMPLETED 8/ 7/91 1:28

ISOTHERM PLOT

% OF MAXIMUM VOLUME VERSUS RELATIVE PRESSURE
10X VOL SORBED = 150.8454 CC/G STP MAX VOL FOR PLOT = 150.8454 CC/G STP



TK-0717
TION 2 STARTED 8/ 6/9 A:26 COMPLETED 8/ 7/91 1:28 NITROGEN

ADSORPTION ISOTHERM

AMPLE WEIGHT: 0.3591 G
REE SPACE: 87.0805 CC
EQUILIBRATION INTERVAL: 10 SECS
MAX VOL INCREMENT: 50.000 CC/G STP

P/PO	VOL ADSORBED (CC/G AT STP)
0.000109	45.625
0.03005	93.245
0.04948	99.385
0.06876	104.14
0.09427	109.33
0.1104	112.25
0.1308	115.60
0.1516	118.60
0.1723	121.43
0.1934	124.06
0.2149	126.47
0.2514	130.09
0.3040	134.41
0.4035	139.86
0.4989	142.58
0.5503	143.61
0.6005	144.33
0.6245	144.63
0.6496	144.99
0.6984	145.69
0.7247	146.12
0.7498	146.42
0.7978	147.01
0.8992	148.53
0.9500	149.43
0.9932	150.85

TK-0717 NITROGEN
T ION 2 STARTED 8/ 6/91 14:26 COMPLETED 8/ 7/91 1:28

SPECIFIC SURFACE AREA

BET SURFACE AREA:	443.0107	+/-	3.1410 SQ M/G
SLOPE:	0.009799	+/-	0.000069
INTERCEPT:	0.000027	+/-	0.000010
C:	358.8519		
VM:	101.7667 CC		
CORRELATION COEFFICIENT	0.9999		

RELATIVE PRESSURE RANGE: 0.0500 TO 0.2100

TK-0717 NITROGEN
T TION 2 STARTED 8/ 6/91 14:26 COMPLETED 8/ 7/91 1:28

ADSORPTION PORE VOLUME AND PORE AREA DISTRIBUTIONS

PORE DIA. RANGE, A	AVERAGE DIA.,A	PORE VOLUME (CC/G)	CUMULATIVE PORE VOLUME	PORE AREA (SQ M/G)	CUMULATIVE PORE AREA
2869.0- 400.4	442.5	0.002177	0.002177	0.197	0.197
400.4- 208.2	244.5	0.001628	0.003805	0.266	0.463
208.2- 106.1	123.3	0.002996	0.006801	0.972	1.435
106.1- 82.2	89.1	0.001174	0.007975	0.527	1.962
82.2- 73.6	76.8	0.000617	0.008592	0.322	2.284
73.6- 66.9	69.6	0.000917	0.009510	0.527	2.811
66.9- 57.3	61.0	0.001523	0.011033	0.999	3.810
57.3- 52.6	54.3	0.000787	0.011819	0.579	4.390
52.6- 49.0	50.5	0.000665	0.012484	0.527	4.916
49.0- 43.2	45.5	0.001629	0.014113	1.432	6.349
43.2- 37.9	39.8	0.002521	0.016633	2.533	8.882
37.9- 30.8	33.2	0.007163	0.023796	8.643	17.524
30.8- 24.6	26.5	0.015661	0.039457	23.674	41.198
24.6- 21.3	22.3	0.012732	0.052190	22.860	64.058
21.3- 19.4	20.0	0.010685	0.062874	21.359	85.417
19.4- 18.2	18.6	0.007107	0.069982	15.306	100.723
18.2- 17.2	17.6	0.007734	0.077716	17.611	118.334
17.2- 16.2	16.6	0.008314	0.086030	20.048	138.382
16.2- 15.3	15.6	0.008605	0.094635	22.035	160.416
15.3- 14.3	14.6	0.009582	0.104217	26.163	186.580
14.3- 13.5	13.8	0.008152	0.112369	23.703	210.283
13.5- 12.3	12.7	0.014052	0.126422	44.116	254.399
12.3- 11.2	11.5	0.012077	0.138499	41.941	296.340
11.2- 9.9	10.3	0.014404	0.152904	55.812	352.152
9.9- 6.2	6.6	0.100605	0.253508	609.438	961.590

LIQUID EQUIVALENT OF MAXIMUM VOLUME SORBED: 0.233328 CC/G

TK-0717 NITROGEN
TATION 2 STARTED 8/ 6/91 14:26 COMPLETED 8/ 7/91 1:28

INCREMENTAL PORE VOLUME DISTRIBUTION (ADSORPTION)

% OF MAXIMUM PORE VOLUME VERSUS AVERAGE PORE DIAMETER, ANGSTROMS
MAX INC PORE VOLUME = 0.100605 CC/G MAX INC FOR PLOT = 0.100605 CC/G

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              20%          40%          60%          80%          100%
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148.5 **
185.0 *
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287.1 *
357.7 *
445.6
555.2
691.7
861.7
1073.5
1337.4
1666.1
2075.7
2585.9
3221.5
4013.4
5000.0
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TK-0717 NITROGEN
TION 2 STARTED 8/ 6/91 14:26 COMPLETED 8/ 7/91 1:28

INCREMENTAL PORE AREA DISTRIBUTION (ADSORPTION)

% OF MAXIMUM PORE AREA VERSUS AVERAGE PORE DIAMETER, ANGSTROMS
MAX INC PORE AREA = 609.438 SQ M/G MAX INC FOR PLOT = 609.438 SQ M/G

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              20%          40%          60%          80%          100%
    I'''''''''''I''''''''''''I''''''''''''I''''''''''''I''''''''''''I
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 25.6 ***
  1.9 *
  9.7
 49.5
 61.6
  6.8
 95.7
119.2
 8.5
 5.0
230.5
 7.1
 7.7
445.6
555.2
 1.7
881.7
073.5
 7.4
 6.1
075.7
 5.9
 1.5
013.4
000.0
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ARC - COAL AND HYDROCARBON PROCESSING DEPT.(SURFACE LABORATORY)

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TK-0722 NITROGEN
TATION 3 STARTED 8/15/91 14:50

PRESSURE (MMHG)	VOL ADSORBED (CC STP/G)	ELAPSED TIME (HR:MN)	SATURATION PRESS (MMHG)	BET SURFACE AREA ESTIMATE (M2/G)
		0: 0	713.842	
0.421	48.8610	0:18		
35.550	83.7724	0:43		
		0:48	713.728	
51.630	88.9140	0:57		
63.999	92.4466	1: 7		
78.362	96.0962	1:14		
92.618	99.4710	1:21		
		1:23	712.748	
107.216	102.6968	1:31		
121.415	105.7506	1:39		
136.191	108.5848	1:45		
150.773	111.2565	1:52		396.073
177.460	115.8756	1:59		
		2: 1	712.063	
215.710	121.6922	2: 8		
284.805	130.1774	2:17		
357.320	135.6687	2:24		
389.611	137.2767	2:29		
425.649	138.6280	2:34		
		2:39	713.508	
444.254	139.2383	2:43		
463.568	139.6916	2:48		
497.848	140.5873	2:52		
517.124	140.9957	2:57		
534.333	141.4717	3: 1		
569.885	142.0926	3: 5		
639.302	143.7528	3:11		
		3:14	712.708	
676.474	144.6423	3:18		
709.757	146.9451	3:25		
		3:27	712.525	

TA 0722 NITROGEN
TION 3 STARTED 8/15/91 14:50 COMPLETED 8/16/91 5:14

ISOTHERM PLOT

% OF MAXIMUM VOLUME VERSUS RELATIVE PRESSURE

AX VOL SORBED = 146.9451 CC/G STP MAX VOL FOR PLOT = 146.9451 CC/G STP

1TK-0722 NITROGEN
STATION 3 STARTED 8/15/91 14:50 COMPLETED 8/16/91 5:14

ADSORPTION ISOTHERM

SAMPLE WEIGHT: 0.2585 G EQUILIBRATION INTERVAL: 10 SECS
FREE SPACE: 85.6044 CC MAX VOL INCREMENT: 50.000 CC/G STP

P/PO	VOL ADSORBED (CC/G AT STP)
0.000590	48.861
0.04981	83.772
0.07236	88.914
0.08973	92.447
0.1099	96.096
0.1299	99.471
0.1505	102.70
0.1704	105.75
0.1912	108.58
0.2117	111.26
0.2492	115.88
0.3028	121.69
0.3996	130.18
0.5012	135.67
0.5463	137.28
0.5967	138.63
0.6227	139.24
0.6499	139.69
0.6980	140.59
0.7252	141.00
0.7494	141.47
0.7994	142.09
0.8969	143.75
0.9492	144.64
0.9961	146.95

91A-0722 NITROGEN
STATION 3 STARTED 8/15/91 14:50 COMPLETED 8/16/91 5:14

SPECIFIC SURFACE AREA

BET SURFACE AREA:	395.9414	+/-	1.1088 SQ M/G
SLOPE:	0.010908	+/-	0.000031
INTERCEPT:	0.000086	+/-	0.000004
C:	127.4746		
VM:	90.9541 CC		
CORRELATION COEFFICIENT	1.0000		

RELATIVE PRESSURE RANGE: 0.0500 TO 0.2100

TK-0722 NITROGEN
TION 3 STARTED 8/15/91 14:50 COMPLETED 8/16/91 5:14

ADSORPTION PORE VOLUME AND PORE AREA DISTRIBUTIONS

PORE DIA. RANGE, A	AVERAGE DIA.,A	PORE VOLUME (CC/G)	CUMULATIVE PORE VOLUME	PORE AREA (SQ M/G)	CUMULATIVE PORE AREA
845.9- 395.0	420.4	0.003330	0.003330	0.317	0.317
395.0- 204.4	240.0	0.001566	0.004896	0.261	0.578
204.4- 107.3	124.5	0.003308	0.008204	1.063	1.641
107.3- 82.8	90.0	0.001236	0.009440	0.550	2.190
82.8- 74.4	77.4	0.001027	0.010467	0.531	2.721
74.4- 67.5	70.3	0.000868	0.011335	0.494	3.215
67.5- 58.0	61.6	0.002019	0.013354	1.310	4.525
58.0- 53.1	54.9	0.001017	0.014371	0.741	5.266
53.1- 49.2	50.7	0.001456	0.015827	1.148	6.414
49.2- 43.4	45.7	0.003348	0.019175	2.932	9.346
43.4- 38.7	40.4	0.004174	0.023349	4.132	13.479
38.7- 31.3	33.7	0.015426	0.038775	18.296	31.775
31.3- 25.2	27.0	0.025478	0.064253	37.760	69.535
25.2- 21.9	22.9	0.017544	0.081796	30.695	100.230
21.9- 19.9	20.6	0.013929	0.095725	27.112	127.342
19.9- 18.8	19.1	0.007921	0.103646	16.576	143.918
18.8- 17.8	18.1	0.008336	0.111982	18.381	162.299
17.8- 16.9	17.2	0.009110	0.121091	21.202	183.501
16.9- 15.9	16.2	0.009345	0.130436	23.012	206.513
15.9- 15.0	15.3	0.009572	0.140009	25.048	231.562
15.0- 14.0	14.3	0.009979	0.149987	27.877	259.439
14.0- 13.1	13.4	0.009395	0.159383	28.115	287.554
13.1- 11.9	12.3	0.012582	0.171965	40.899	328.452
11.9- 7.7	8.3	0.075279	0.247243	363.975	692.428

LIQUID EQUIVALENT OF MAXIMUM VOLUME SORBED: 0.227295 CC/G

ITK-0722 NITROGEN
STATION 3 STARTED 8/15/91 14:50 COMPLETED 8/16/91 5:14

INCREMENTAL PORE VOLUME DISTRIBUTION (ADSORPTION)

% OF MAXIMUM PORE VOLUME VERSUS AVERAGE PORE DIAMETER, ANGSTROMS
MAX INC PORE VOLUME = 0.075279 CC/G MAX INC FOR PLOT = 0.075279 CC/G

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                20%          40%          60%          80%          100%
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230.5 *
287.1 **
357.7 **
445.6
555.2
691.7
861.7
1073.5
1337.4
1666.1
2075.7
2585.9
3221.5
4013.4
5000.0
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TK-0722 NITROGEN
STATION 3 STARTED 8/15/91 14:50 COMPLETED 8/16/91 5:14

INCREMENTAL PORE AREA DISTRIBUTION (ADSORPTION)

% OF MAXIMUM PORE AREA VERSUS AVERAGE PORE DIAMETER, ANGSTROMS
MAX INC PORE AREA = 363.975 SQ M/G MAX INC FOR PLOT = 363.975 SQ M/G

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                20%          40%          60%          80%          100%
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 185.0
 230.5
 287.1
 357.7
 445.6
 555.2
 691.7
 861.7
1073.5
1337.4
1666.1
2075.7
2585.9
3221.5
4013.4
5000.0
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ARC - COAL AND HYDROCARBON PROCESSING DEPT.(SURFACE LABORATORY)

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TK-0722 NITROGEN
TATION 3 STARTED 8/ 6/91 14:26

PRESSURE (MMHG)	VOL ADSORBED (CC STP/G)	ELAPSED TIME (HR:MN)	SATURATION PRESS (MMHG)	BET SURFACE AREA ESTIMATE (M2/G)
		0: 0	716.407	
0.180	49.3154	0:19		
33.156	95.2297	0:40		
		0:42	715.776	
36.047	96.4337	0:51		
49.726	101.3647	1: 1		
63.783	105.8493	1: 9		
78.345	109.9992	1:16		
		1:19	714.192	
93.027	113.9139	1:28		
107.025	117.4308	1:35		
121.711	120.9114	1:42		
136.149	124.0985	1:50		
		1:52	713.392	
151.217	127.2213	1:59		451.394
177.641	132.3831	2: 7		
216.054	138.9466	2:15		
285.368	148.3988	2:23		
		2:25	714.133	
357.599	154.5892	2:31		
390.509	156.6193	2:36		
427.576	158.1165	2:41		
445.509	158.6538	2:46		
463.081	159.3499	2:50		
498.665	160.6352	2:55		
		2:58	712.698	
517.451	161.1491	3: 2		
534.063	161.3638	3: 6		
567.751	162.3002	3:11		
641.218	164.4769	3:19		
676.813	165.7474	3:23		
		3:26	714.284	
710.578	168.5941	3:33		
		3:35	714.305	

ARC - COAL AND HYDROCARBON PROCESSING DEPT.(SURFACE LABORATORY)

DIGISORB 2600 V3.03 PAGE 2
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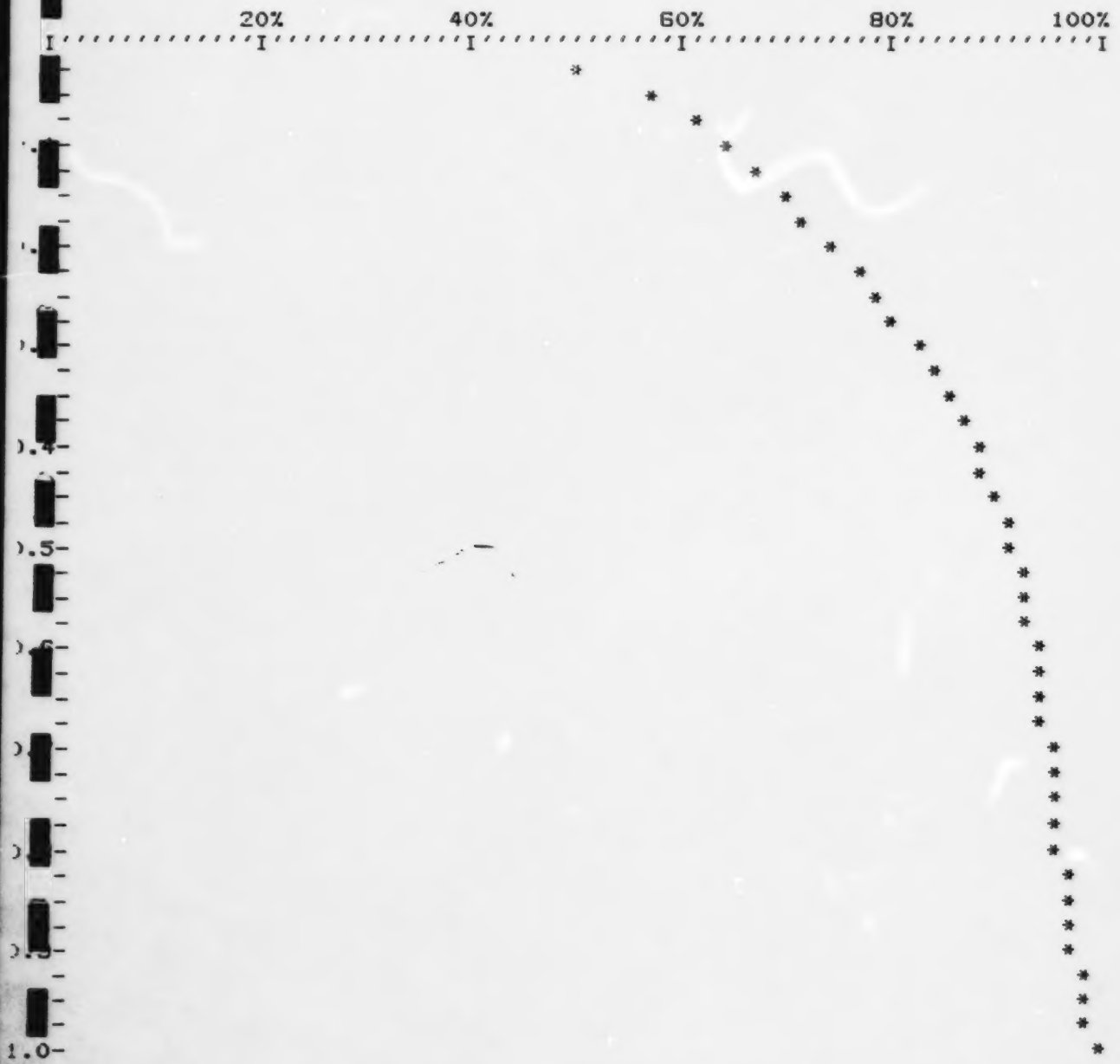
T -0722 NITROGEN
TION 3 STARTED 8/ 6/91 14:26 COMPLETED 8/ 7/91 5:14

ISOTHERM PLOT

% OF MAXIMUM VOLUME VERSUS RELATIVE PRESSURE
AX VOL SORBED = 168.5941 CC/G STP MAX VOL FOR PLOT = 168.5941 CC/G STP



TK-0722 NITROGEN
T TION 3 STARTED 8/ 6/91 14:26 COMPLETED 8/ 7/91 5:14

ADSORPTION ISOTHERM

AMPLE WEIGHT: 0.2296 G EQUILIBRATION INTERVAL: 10 SECS
REE SPACE: 84.2480 CC MAX VOL INCREMENT: 50.000 CC/G STP

P/PO	VOL ADSORBED (CC/G AT STP)
0.000252	49.315
0.04632	95.230
0.05039	96.434
0.06955	101.36
0.08925	105.85
0.1097	110.00
0.1303	113.91
0.1499	117.43
0.1706	120.91
0.1908	124.10
0.2119	127.22
0.2489	132.38
0.3026	138.95
0.3996	148.40
0.5009	154.59
0.5472	156.62
0.5993	158.12
0.6246	158.65
0.6494	159.35
0.6996	160.64
0.7258	161.15
0.7489	161.36
0.7958	162.30
0.8982	164.48
0.9477	165.75
0.9948	168.59

TK-0722 NITROGEN
T TION 3 STARTED 8/ 6/91 14:26 COMPLETED 8/ 7/91 5:14

SPECIFIC SURFACE AREA

BET SURFACE AREA:	451.3378	+/-	0.9433 SQ M/G
SLOPE:	0.009576	+/-	0.000020
INTERCEPT:	0.000069	+/-	0.000003
C:	139.2408		
VM:	103.6796 CC		
CORRELATION COEFFICIENT	1.0000		

RELATIVE PRESSURE RANGE: 0.0500 TO 0.2100

ITK-0722
STION 3 STARTED 8/ 6/91 14:26 COMPLETED 8/ 7/91 5:14 NITROGEN

ADSORPTION PORE VOLUME AND PORE AREA DISTRIBUTIONS

PORE DIA. RANGE, A	AVERAGE DIA.,A	PORE VOLUME (CC/G)	CUMULATIVE PORE VOLUME	PORE AREA (SQ M/G)	CUMULATIVE PORE AREA
3732.3- 383.6	414.5	0.004232	0.004232	0.408	0.408
383.6- 206.0	241.5	0.002254	0.006486	0.373	0.782
206.0- 105.3	122.3	0.004296	0.010782	1.405	2.187
105.3- 82.1	88.8	0.001897	0.012679	0.854	3.041
82.1- 74.1	77.0	0.000376	0.013054	0.195	3.236
74.1- 67.4	70.1	0.001088	0.014142	0.621	3.856
67.4- 57.6	61.3	0.002894	0.017036	1.888	5.745
57.6- 52.9	54.5	0.001595	0.018631	1.169	6.914
52.9- 49.2	50.6	0.001190	0.019821	0.940	7.854
49.2- 43.1	45.5	0.003570	0.023391	3.142	10.996
43.1- 38.3	40.0	0.005174	0.028565	5.174	16.169
38.3- 30.8	33.3	0.016846	0.045411	20.244	36.413
30.8- 24.8	26.6	0.027350	0.072761	41.201	77.614
24.8- 21.5	22.4	0.019033	0.091794	33.958	111.572
21.5- 19.5	20.1	0.014930	0.106723	29.685	141.257
19.5- 18.3	18.7	0.008864	0.115587	18.978	160.235
18.3- 17.4	17.7	0.008989	0.124576	20.309	180.544
17.4- 16.4	16.7	0.009764	0.134340	23.317	203.862
16.4- 15.5	15.8	0.009684	0.144024	24.506	228.368
15.5- 14.5	14.9	0.010477	0.154501	28.197	256.565
14.5- 13.5	13.9	0.010611	0.165112	30.599	287.164
13.5- 12.5	12.9	0.010986	0.176099	34.174	321.338
12.5- 11.5	11.8	0.011068	0.187167	37.500	358.838
11.5- 11.0	11.0	0.002583	0.189750	9.350	368.188
11.0- 7.0	7.5	0.090822	0.280571	487.398	855.586

LIQUID EQUIVALENT OF MAXIMUM VOLUME SORBED: 0.260781 CC/G

TK-0722 NITROGEN
TATION 3 STARTED 8/ 6/91 14:26 COMPLETED 8/ 7/91 5:14

INCREMENTAL PORE VOLUME DISTRIBUTION (ADSORPTION)

% OF MAXIMUM PORE VOLUME VERSUS AVERAGE PORE DIAMETER, ANGSTROMS
MAX INC PORE VOLUME = 0.090822 CC/G MAX INC FOR PLOT = 0.090822 CC/G

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                20%          40%          60%          80%          100%
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 25.6 ******************
 31.9 ************
 38.7 ****
 49.5 *
 61.6 **
 76.8
 95.7 **
119.2 ***
148.5 ***
185.0 **
230.5 **
287.1 **
357.7 ***
445.6
555.2
691.7
861.7
1073.5
1337.4
1666.1
2075.7
2585.9
3221.5
4013.4
5000.0
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TK-0722 NITROGEN
TATION 3 STARTED 8/ 6/91 14:26 COMPLETED 8/ 7/91 5:14

INCREMENTAL PORE AREA DISTRIBUTION (ADSORPTION)

% OF MAXIMUM PORE AREA VERSUS AVERAGE PORE DIAMETER, ANGSTROMS
MAX INC PORE AREA = 487.398 SQ M/G MAX INC FOR PLOT = 487.398 SQ M/G

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              20%          40%          60%          80%          100%
    I'''''''''''I''''''''''''I''''''''''''I''''''''''''I''''''''''''I
  [illegible]3.5
  [illegible]4.4
   5.5
   6.8
  [illegible]8.5 **********************************************
  [illegible]0.6 ********
  13.2 ****
  [illegible]6.5 ***
  [illegible]0.5 ****
  25.6 *****
  [illegible]1.9 ***
  [illegible]9.7 *
  49.5
  61.6
  [illegible]6.8
  [illegible]5.7
 119.2
 [illegible]8.5
 [illegible]5.0
 230.5
 [illegible]7.1
 [illegible]7.7
 [illegible]5.6
 555.2
 [illegible]1.7
 [illegible]1.7
1073.5
[illegible]7.4
[illegible]6.1
2075.7
2585.9
[illegible]1.5
[illegible]3.4
5000.0
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ARC - COAL AND HYDROCARBON PROCESSING DEPT.(SURFACE LABORATORY)

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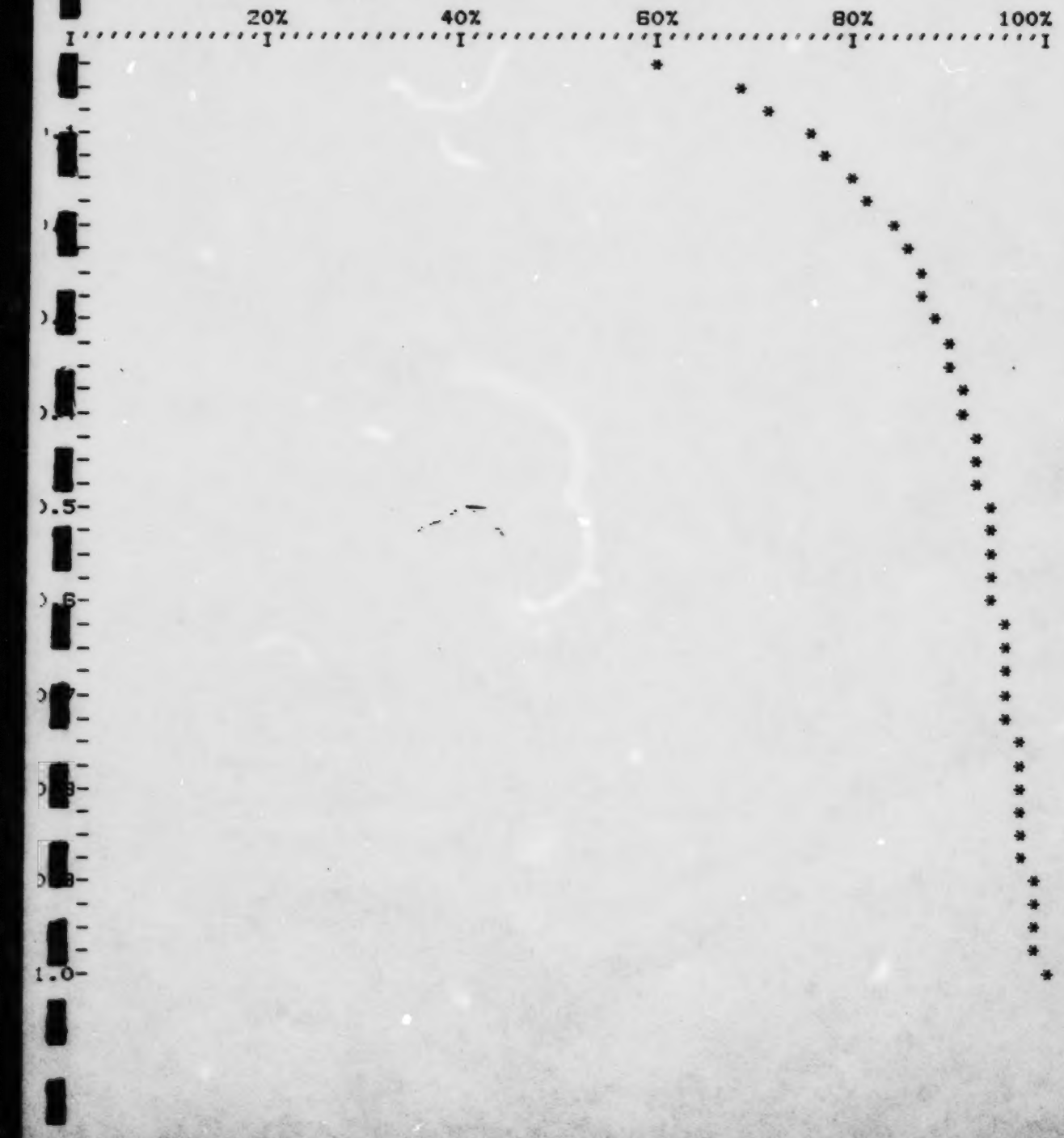
TK-072#
TION 4 STARTED 8/ 6/91 14:26 NITROGEN

PRESSURE (MMHG)	VOL ADSORBED (CC STP/G)	ELAPSED TIME (HR:MN)	SATURATION PRESS (MMHG)	BET SURFACE AREA ESTIMATE (M2/G)
		0: 0	714.305	
0.166	48.5399	0:18		
35.013	88.7911	0:47		
		0:51	713.580	
54.079	94.0624	1: 0		
62.837	96.1434	1: 8		
78.035	99.4081	1:16		
93.324	101.9936	1:23		
		1:27	713.494	
108.162	104.3916	1:35		
122.810	106.5304	1:43		
137.625	108.4515	1:49		
152.943	110.2358	1:55		383.894
178.691	112.8715	2: 2		
		2: 7	713.350	
215.927	116.0366	2:14		
286.149	120.0465	2:20		
355.460	122.3080	2:26		
380.480	123.0602	2:30		
426.879	123.6986	2:35		
445.420	123.9022	2:39		
		2:41	712.894	
462.525	124.3628	2:45		
487.902	125.1447	2:49		
516.457	125.3591	2:54		
533.114	125.8660	2:58		
569.473	126.4893	3: 3		
639.803	127.7899	3: 8		
675.379	128.5131	3:13		
		3:15	712.945	
710.850	130.3960	3:24		
		3:26	712.878	

TK-0725 NITROGEN
TATION 4 STARTED 8/ 6/91 14:26 COMPLETED 8/ 7/91 8:51

ISOTHERM PLOT

% OF MAXIMUM VOLUME VERSUS RELATIVE PRESSURE
MAX VOL SORBED = 130.3960 CC/G STP MAX VOL FOR PLOT = 130.3960 CC/G STP



TA-0725 NITROGEN
STATION 4 STARTED 8/ 6/91 14:26 COMPLETED 8/ 7/91 8:51

ADSORPTION ISOTHERM

SAMPLE WEIGHT: 0.2966 G EQUILIBRATION INTERVAL: 10 SECS
FREE SPACE: 85.7048 CC MAX VOL INCREMENT: 50.000 CC/G STP

P/PO	VOL ADSORBED (CC/G AT STP)
0.000232	48.540
0.04906	88.791
0.07579	94.062
0.08806	96.143
0.1108	99.408
0.1308	101.99
0.1516	104.39
0.1721	106.53
0.1929	108.45
0.2144	110.24
0.2505	112.87
0.3027	116.04
0.4012	120.05
0.4985	122.31
0.5476	123.06
0.5987	123.70
0.6248	123.90
0.6488	124.36
0.6984	125.14
0.7244	125.36
0.7478	125.87
0.7988	126.49
0.8974	127.79
0.9473	128.51
0.9971	130.40

TK-0725 NITROGEN
TATION 4 STARTED 8/ 6/91 14:26 COMPLETED 8/ 7/91 8:51

SPECIFIC SURFACE AREA

BET SURFACE AREA:	383.8772	+/-	3.3513 SQ M/G
SLOPE:	0.011337	+/-	0.000098
INTERCEPT:	0.000003	+/-	0.000014
C:	4342.9248		
VM:	88.1828 CC		
CORRELATION COEFFICIENT	0.9998		

RELATIVE PRESSURE RANGE: 0.0500 TO 0.2100

TK-0725 NITROGEN
T TION 4 STARTED 8/ 6/91 14:26 COMPLETED 8/ 7/91 8:51

ADSORPTION PORE VOLUME AND PORE AREA DISTRIBUTIONS

PORE DIA. RANGE, A	AVERAGE DIA.,A	PORE VOLUME (CC/G)	CUMULATIVE PORE VOLUME	PORE AREA (SQ M/G)	CUMULATIVE PORE AREA
739.7- 380.9	398.5	0.002591	0.002591	0.260	0.260
380.9- 204.8	240.0	0.001278	0.003869	0.213	0.473
204.8- 106.9	124.1	0.002580	0.006449	0.831	1.304
106.9- 82.2	89.4	0.001275	0.007724	0.570	1.875
82.2- 74.1	77.0	0.001117	0.008841	0.580	2.455
74.1- 67.5	70.1	0.000414	0.009255	0.236	2.691
67.5- 57.8	61.5	0.001761	0.011016	1.146	3.837
57.8- 53.2	54.9	0.001073	0.012088	0.782	4.619
53.2- 49.4	51.0	0.000391	0.012479	0.307	4.926
49.4- 43.5	45.8	0.001457	0.013936	1.272	6.198
43.5- 38.4	40.2	0.001827	0.015763	1.816	8.014
38.4- 31.2	33.6	0.006101	0.021863	7.257	15.271
31.2- 25.1	26.9	0.011878	0.033741	17.632	32.903
25.1- 21.9	22.8	0.009735	0.043476	17.071	49.974
21.9- 19.9	20.6	0.008186	0.051662	15.922	65.896
19.9- 18.8	19.1	0.005553	0.057215	11.605	77.501
18.8- 17.8	18.1	0.006021	0.063236	13.278	90.778
17.8- 16.8	17.2	0.006758	0.069995	15.740	106.519
16.8- 15.9	16.2	0.007563	0.077558	18.663	125.182
15.9- 14.9	15.2	0.008113	0.085671	21.286	146.468
14.9- 13.9	14.2	0.010044	0.095715	28.245	174.713
13.9- 13.1	13.3	0.006368	0.102082	19.136	193.849
13.1- 11.9	12.3	0.015640	0.117722	50.849	244.698
11.9- 7.4	7.8	0.106317	0.224039	543.460	788.158

LIQUID EQUIVALENT OF MAXIMUM VOLUME SORBED: 0.201697 CC/G

TK-0725 NITROGEN
TION 4 STARTED 8/ 6/91 14:26 COMPLETED 8/ 7/91 8:51

INCREMENTAL PORE VOLUME DISTRIBUTION (ADSORPTION)

% OF MAXIMUM PORE VOLUME VERSUS AVERAGE PORE DIAMETER, ANGSTROMS
MAX INC PORE VOLUME = 0.106317 CC/G MAX INC FOR PLOT = 0.106317 CC/G

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                20%          40%          60%          80%          100%
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119.2 *
148.5 *
185.0 *
230.5 *
287.1 *
357.7 *
445.6
555.2
691.7
861.7
1073.5
1337.4
1666.1
2075.7
2585.9
3221.5
4013.4
5000.0
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!TK-0725 NITROGEN
:TION 4 STARTED 8/ 6/91 14:26 COMPLETED 8/ 7/91 8:51

INCREMENTAL PORE AREA DISTRIBUTION (ADSORPTION)

% OF MAXIMUM PORE AREA VERSUS AVERAGE PORE DIAMETER, ANGSTROMS
MAX INC PORE AREA = 543.460 SQ M/G MAX INC FOR PLOT = 543.460 SQ M/G

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                20%          40%          60%          80%         100%
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20.5 **
25.6 **
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95.7
119.2
148.5
185.0
230.5
287.1
357.7
445.6
555.2
691.7
861.7
1073.5
1337.4
1666.1
2075.7
2585.9
3221.5
4013.4
5000.0
```

ARC - COAL AND HYDROCARBON PROCESSING DEPT.(SURFACE LABORATORY)

DIGISORB 2600 V3.03

105

'TK-0729 NITROGEN

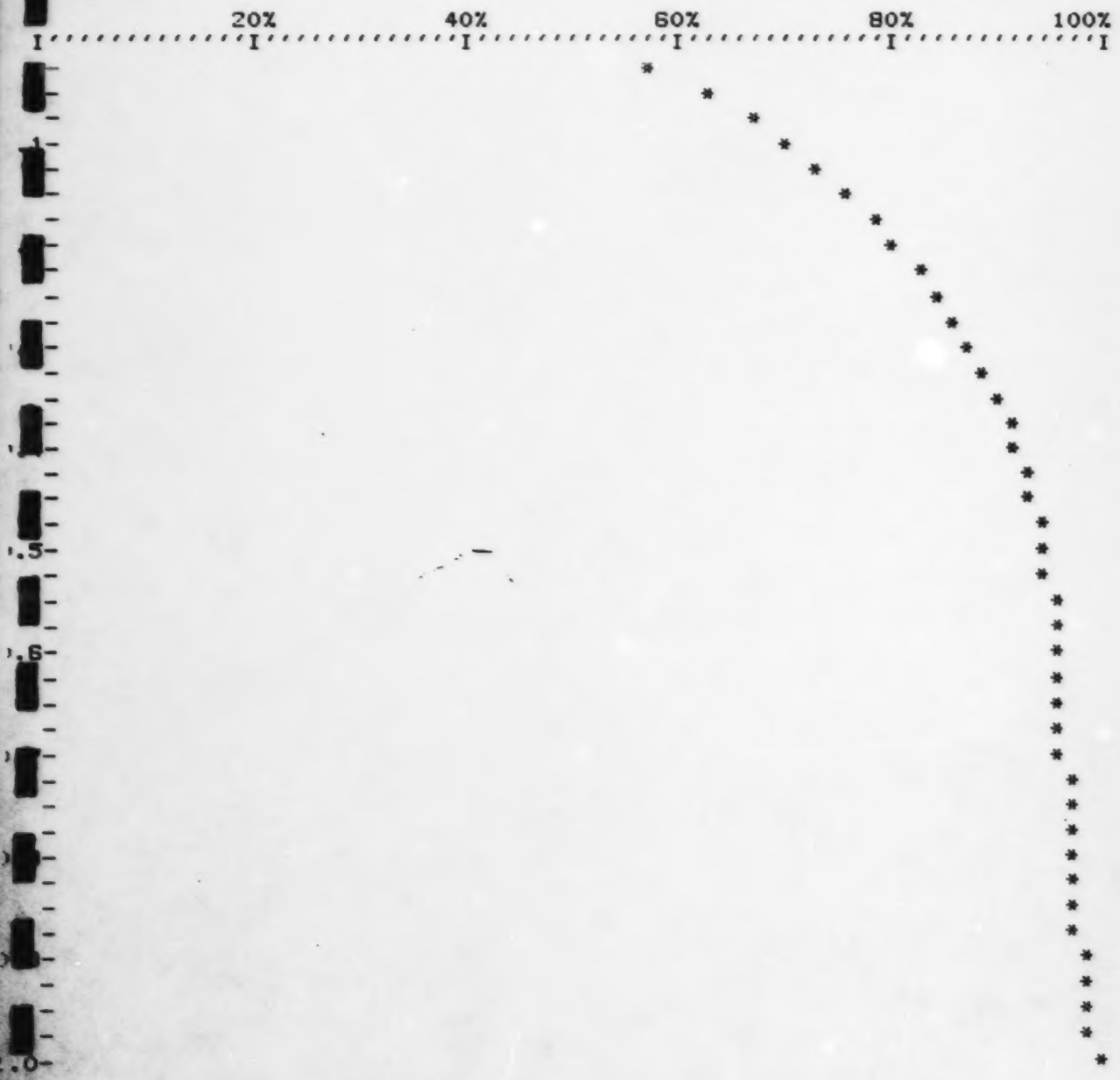
TATION 5 STARTED 8/ 6/91 14:26

PRESSURE (MMHG)	VOL ADSORBED (CC STP/G)	ELAPSED TIME (HR:MN)	SATURATION PRESS (MMHG)	BET SURFACE AREA ESTIMATE (M2/G)
		0: 0	712.878	
0.024	49.3665	0:19		
		0:23	712.256	
0.529	98.3188	0:43		
21.925	148.9862	1: 6		
		1: 8	710.812	
35.565	159.0496	1:26		
48.776	166.7968	1:40		
		1:44	711.658	
62.950	173.9920	1:55		
77.828	180.7101	2: 4		
92.440	186.7120	2:15		
		2:17	711.528	
107.258	192.1909	2:28		
122.090	197.4064	2:37		
136.886	202.1567	2:46		
152.531	206.6419	2:54		730.362
		2:57	711.527	
178.455	213.5101	3: 6		
216.675	222.0683	3:16		
287.819	233.1674	3:26		
355.545	238.7857	3:34		
		3:36	711.516	
390.962	240.6915	3:44		
428.208	241.9754	3:49		
444.455	242.3283	3:53		
461.296	242.9368	3:58		
496.694	243.9749	4: 3		
515.241	244.3895	4: 7		
		4: 9	710.169	
532.281	245.0530	4:13		
566.965	246.0072	4:18		
637.047	248.2246	4:24		
673.157	249.4172	4:29		
		4:31	710.861	
706.724	253.0434	4:39		
		4:41	711.379	

TK-0729 NITROGEN
TATION 5 STARTED 8/ 6/91 14:26 COMPLETED 8/ 7/91 13:43

ISOTHERM PLOT

% OF MAXIMUM VOLUME VERSUS RELATIVE PRESSURE
AX VOL SORBED = 253.0434 CC/G STP MAX VOL FOR PLOT = 253.0434 CC/G STP



TK-0729 NITROGEN
T TION 5 STARTED 8/ 6/91 14:26 COMPLETED 8/ 7/91 13:43

ADSORPTION ISOTHERM

AMPLE WEIGHT: 0.2579 G EQUILIBRATION INTERVAL: 10 SECS
REE SPACE: 85.2726 CC MAX VOL INCREMENT: 50.000 CC/G STP

P/PO	VOL ADSORBED (CC/G AT STP)
0.000034	49.366
0.000743	98.319
0.03084	148.99
0.05000	159.05
0.06855	166.80
0.08846	173.99
0.1094	180.71
0.1299	186.71
0.1507	192.19
0.1716	197.41
0.1924	202.16
0.2144	206.64
0.2508	213.51
0.3045	222.07
0.4045	233.17
0.4997	238.79
0.5497	240.69
0.6023	241.98
0.6253	242.33
0.6491	242.94
0.6991	243.97
0.7254	244.39
0.7494	245.05
0.7980	246.01
0.8965	248.22
0.9471	249.42
0.9936	253.04

TK-0729 NITROGEN
TATION 5 STARTED 8/ 6/91 14:26 COMPLETED 8/ 7/91 :3:43

SPECIFIC SURFACE AREA

BET SURFACE AREA:	730.3674	+/-	2.8507 SQ M/G
SLOPE:	0.005927	+/-	0.000023
INTERCEPT:	0.000033	+/-	0.000003
C:	180.4981		
VM:	167.7772 CC		
CORRELATION COEFFICIENT	1.0000		

RELATIVE PRESSURE RANGE: 0.0500 TO 0.2100

1TK-0729 NITROGEN
STATION 5 STARTED 8/ 6/91 14:26 COMPLETED 8/ 7/91 13:43

ADSORPTION PORE VOLUME AND PORE AREA DISTRIBUTIONS

PORE DIA. RANGE, A	AVERAGE DIA.,A	PORE VOLUME (CC/G)	CUMULATIVE PORE VOLUME	PORE AREA (SQ M/G)	CUMULATIVE PORE AREA
3016.5- 377.8	413.8	0.005481	0.005481	0.530	0.530
377.8- 201.7	236.6	0.002046	0.007526	0.346	0.876
201.7- 105.1	122.2	0.004282	0.011809	1.401	2.277
105.1- 81.3	88.3	0.001870	0.013679	0.847	3.124
81.3- 73.0	76.0	0.001376	0.015054	0.724	3.848
73.0- 66.3	69.0	0.000801	0.015855	0.464	4.312
66.3- 56.5	60.2	0.002175	0.018030	1.445	5.757
56.5- 51.9	53.6	0.001323	0.019353	0.988	6.745
51.9- 48.5	49.9	0.000698	0.020050	0.559	7.304
48.5- 42.4	44.8	0.002872	0.022922	2.566	9.871
42.4- 37.2	39.0	0.004580	0.027503	4.692	14.563
37.2- 30.1	32.4	0.014412	0.041915	17.769	32.331
30.1- 23.9	25.7	0.030294	0.072208	47.102	79.433
23.9- 20.5	21.5	0.023438	0.095646	43.607	123.040
20.5- 18.6	19.2	0.018611	0.114258	38.764	161.805
18.6- 17.4	17.8	0.011891	0.126149	26.780	188.585
17.4- 16.4	16.7	0.012597	0.138746	30.087	218.672
16.4- 15.4	15.8	0.013708	0.152454	34.761	253.432
15.4- 14.5	14.8	0.013962	0.166416	37.730	291.162
14.5- 13.5	13.8	0.015005	0.181421	43.411	334.573
13.5- 12.5	12.8	0.016134	0.197555	50.313	384.886
12.5- 11.5	11.8	0.016336	0.213891	55.405	440.292
11.5- 10.4	10.7	0.016240	0.230131	60.450	500.742
10.4- 9.2	9.6	0.019015	0.249146	79.324	580.066
9.2- 6.0	6.5	0.077181	0.326327	474.519	1054.586
6.0- 3.5	3.7	0.091390	0.417717	984.062	2038.648

LIQUID EQUIVALENT OF MAXIMUM VOLUME SORBED: 0.391408 CC/G

ITK-0729 NITROGEN
STATION 5 STARTED 8/ 6/91 14:26 COMPLETED 8/ 7/91 13:43

INCREMENTAL PORE VOLUME DISTRIBUTION (ADSORPTION)

% OF MAXIMUM PORE VOLUME VERSUS AVERAGE PORE DIAMETER, ANGSTROMS
MAX INC PORE VOLUME = 0.091390 CC/G MAX INC FOR PLOT = 0.091390 CC/G

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              20%          40%          60%          80%         100%
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 119.2 ***
 148.5 ***
 185.0 **
 230.5 **
 287.1 **
 357.7 ***
 445.6
 555.2
 691.7
 861.7
1073.5
1337.4
1666.1
2075.7
2585.9
3221.5
4013.4
5000.0
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TK-0729 NITROGEN
TATION 5 STARTED 8/ 6/91 14:26 COMPLETED 8/ 7/91 13:43

INCREMENTAL PORE AREA DISTRIBUTION (ADSORPTION)

% OF MAXIMUM PORE AREA VERSUS AVERAGE PORE DIAMETER, ANGSTROMS
MAX INC PORE AREA = 984.062 SQ M/G MAX INC FOR PLOT = 984.062 SQ M/G

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              20%          40%          60%          80%          100%
    I'''''''''''I''''''''''''I''''''''''''I''''''''''''I''''''''''''I
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95.7
119.2
148.5
185.0
230.5
287.1
357.7
445.6
555.2
691.7
861.7
1073.5
1337.4
1666.1
2075.7
2585.9
3221.5
4013.4
5000.0
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ARC - COAL AND HYDROCARBON PROCESSING DEPT.(SURFACE LABORATORY)

DIGISORB 2600 V3.03 PAGE 1
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1TK-0807 NITROGEN
STATION 4 STARTED 8/15/91 14:50

PRESSURE (MMHG)	VOL ADSORBED (CC STP/G)	ELAPSED TIME (HR:MN)	SATURATION PRESS (MMHG)	BET SURFACE AREA ESTIMATE (M2/G)
		0: 0	712.525	
0.060	49.0407	0:19		
6.973	96.4101	0:49		
		0:54	713.516	
35.508	116.0633	1:18		
51.980	122.4957	1:27		
		1:30	710.607	
63.923	126.5803	1:44		
78.384	130.8370	1:52		
92.840	134.6516	2: 0		
		2: 2	711.494	
107.448	138.1194	2:11		
122.101	141.4568	2:19		
137.234	144.3833	2:26		
152.245	147.1266	2:33		515.660
		2:35	712.060	
178.332	151.2883	2:43		
215.959	156.2462	2:50		
286.286	162.4975	2:58		
355.084	165.6677	3: 3		
389.185	166.6101	3: 8		
		3:10	712.718	
425.255	167.5489	3:14		
445.197	167.8848	3:18		
462.673	168.1737	3:22		
497.276	169.0573	3:27		
516.741	169.3704	3:31		
533.598	169.7586	3:35		
568.943	170.4023	3:40		
		3:41	712.934	
639.091	171.8656	3:47		
675.224	172.9355	3:51		
		3:54	713.866	
710.863	175.6684	4: 1		
		4: 3	713.811	

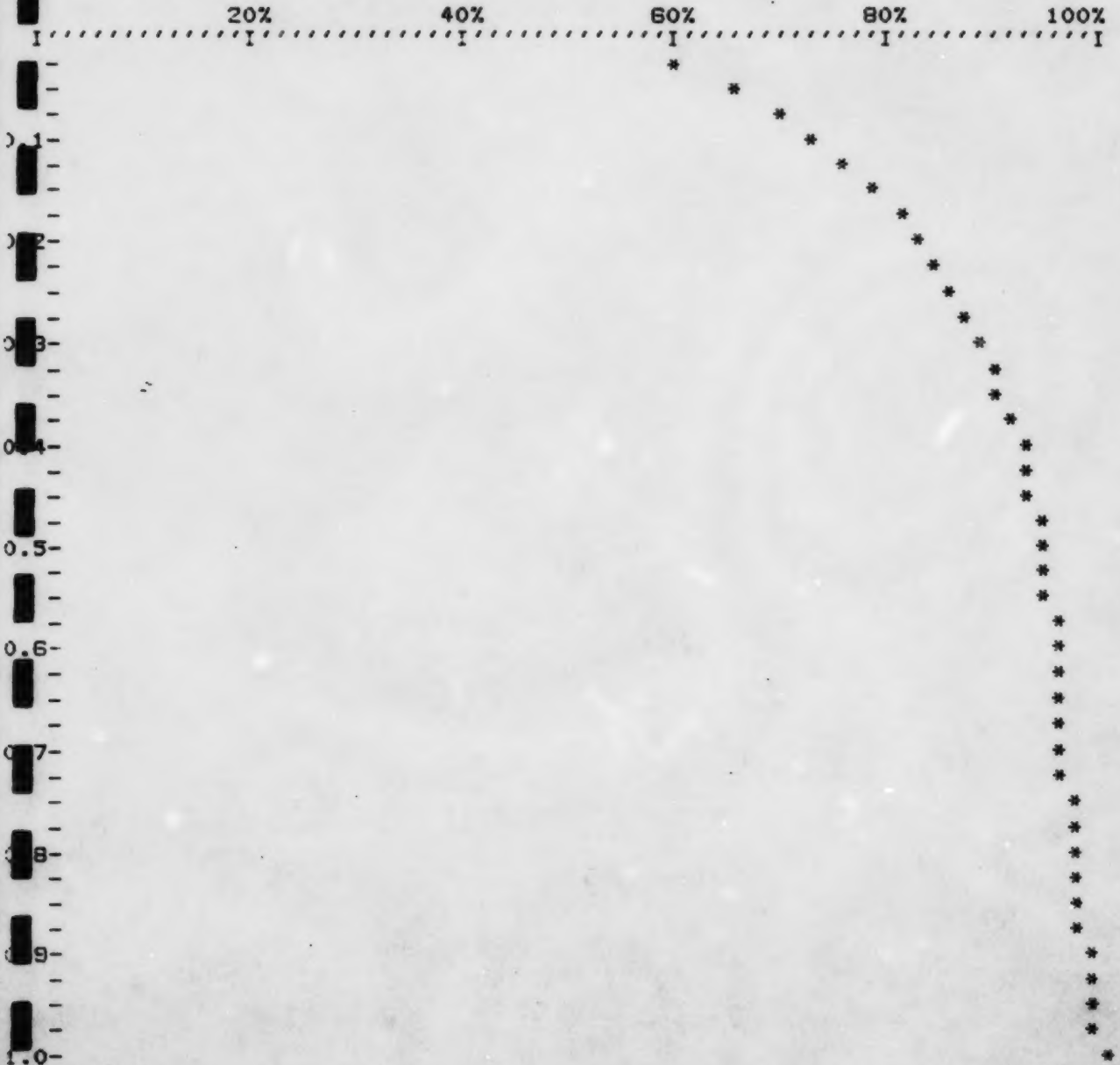
ARC - COAL AND HYDROCARBON PROCESSING DEPT.(SURFACE LABORATORY)

DIGISORB 2600 V3.03 PAGE 2
105

1TK-0807 NITROGEN
STATION 4 STARTED 8/15/91 14:50 COMPLETED 8/16/91 9:28

ISOTHERM PLOT

% OF MAXIMUM VOLUME VERSUS RELATIVE PRESSURE
MAX VOL SORBED = 175.6684 CC/G STP MAX VOL FOR PLOT = 175.6684 CC/G STP



STK-0807 NITROGEN
STATION 4 STARTED 8/15/91 14:50 COMPLETED 8/16/91 9:28

ADSORPTION ISOTHERM

SAMPLE WEIGHT: 0.2499 G EQUILIBRATION INTERVAL: 10 SECS
FREE SPACE: 85.6134 CC MAX VOL INCREMENT: 50.000 CC/G STP

P/PO	VOL ADSORBED (CC/G AT STP)
0.000085	49.041
0.009774	96.410
0.04990	116.06
0.07313	122.50
0.08990	126.58
0.1102	130.84
0.1305	134.65
0.1510	138.12
0.1715	141.46
0.1928	144.38
0.2138	147.13
0.2504	151.29
0.3032	156.25
0.4018	162.50
0.4983	165.67
0.5461	166.61
0.5966	167.55
0.6246	167.88
0.6491	168.17
0.6976	169.06
0.7249	169.37
0.7485	169.76
0.7980	170.40
0.8959	171.87
0.9461	172.94
0.9959	175.67

1TK-0807 NITROGEN
STATION 4 STARTED 8/15/91 14:50 COMPLETED 8/16/91 9:28

SPECIFIC SURFACE AREA

BET SURFACE AREA:	515.8031	+/-	3.7509 SQ M/G
SLOPE:	0.008417	+/-	0.000061
INTERCEPT:	0.000022	+/-	0.000008
C:	380.9407		
VM:	118.4883 CC		
CORRELATION COEFFICIENT	0.9999		

RELATIVE PRESSURE RANGE: 0.0500 TO 0.2100

MTK-0807 NITROGEN
STATION 4 STARTED 8/15/91 14:50 COMPLETED 8/16/91 9:28

ADSORPTION PORE VOLUME AND PORE AREA DISTRIBUTIONS

PORE DIA. RANGE, A	AVERAGE DIA.,A	PORE VOLUME (CC/G)	CUMULATIVE PORE VOLUME	PORE AREA (SQ M/G)	CUMULATIVE PORE AREA
652.9- 371.7	395.4	0.003920	0.003920	0.396	0.396
371.7- 201.1	235.6	0.001879	0.005798	0.319	0.715
201.1- 105.6	122.7	0.002806	0.008604	0.915	1.630
105.6- 81.5	88.6	0.001264	0.009868	0.571	2.201
81.5- 73.4	76.3	0.000802	0.010671	0.421	2.622
73.4- 66.4	69.2	0.000622	0.011293	0.359	2.981
66.4- 57.0	60.6	0.001941	0.013234	1.282	4.263
57.0- 52.4	54.0	0.000591	0.013825	0.437	4.700
52.4- 48.3	49.9	0.000701	0.014526	0.562	5.262
48.3- 42.4	44.7	0.002178	0.016705	1.949	7.211
42.4- 37.5	39.3	0.002229	0.018934	2.269	9.479
37.5- 30.4	32.8	0.008280	0.027213	10.101	19.580
30.4- 24.3	26.1	0.017690	0.044903	27.091	46.671
24.3- 21.0	22.0	0.014279	0.059183	26.006	72.677
21.0- 19.1	19.7	0.011983	0.071166	24.342	97.019
19.1- 17.9	18.3	0.007863	0.079029	17.220	114.239
17.9- 16.9	17.3	0.008286	0.087315	19.194	133.434
16.9- 15.9	16.3	0.009594	0.096909	23.561	156.995
15.9- 15.0	15.3	0.009685	0.106595	25.272	182.267
15.0- 14.0	14.4	0.010503	0.117097	29.236	211.503
14.0- 13.1	13.4	0.011420	0.128517	34.112	245.614
13.1- 12.2	12.5	0.010737	0.139255	34.496	280.110
12.2- 11.0	11.4	0.015744	0.154999	55.281	335.390
11.0- 8.4	9.0	0.042011	0.197010	186.253	521.644
8.4- 5.1	5.6	0.097381	0.294391	701.686	1223.330

LIQUID EQUIVALENT OF MAXIMUM VOLUME SORBED: 0.271724 CC/G

ITK-0807 NITROGEN
STION 4 STARTED 8/15/91 14:50 COMPLETED 8/16/91 9:28

INCREMENTAL PORE VOLUME DISTRIBUTION (ADSORPTION)

% OF MAXIMUM PORE VOLUME VERSUS AVERAGE PORE DIAMETER, ANGSTROMS
MAX INC PORE VOLUME = 0.097381 CC/G MAX INC FOR PLOT = 0.097381 CC/G

```
              20%          40%          60%          80%          100%
     .....|.....|.....|.....|.....|.....|.....|.....|.....|.....|
   3.5
   4.4
   5.5
   6.8 ****************************************************
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  39.7 *
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 119.2 **
 148.5 **
 185.0 *
 230.5 *
 287.1 **
 357.7 **
 445.6
 555.2
 691.7
 861.7
1073.5
1337.4
1666.1
2075.7
2585.9
3221.5
4013.4
5000.0
```

1TK-0807 NITROGEN
STATION 4 STARTED 8/15/91 14:50 COMPLETED 8/16/91 9:28

INCREMENTAL PORE AREA DISTRIBUTION (ADSORPTION)

% OF MAXIMUM PORE AREA VERSUS AVERAGE PORE DIAMETER, ANGSTROMS
MAX INC PORE AREA = 701.686 SQ M/G MAX INC FOR PLOT = 701.686 SQ M/G

```
                20%          40%          60%          80%         100%
     I''''''''''''I''''''''''''I''''''''''''I''''''''''''I''''''''''''I
   3.5
   4.4
   5.5
   6.8 ************************************************
   8.5 ************************
  10.6 *********
  13.2 ***
  16.5 **
  20.5 **
  25.6 **
  31.9 *
  39.7
  49.5
  61.6
  76.8
  95.7
 119.2
 148.5
 185.0
 230.5
 287.1
 357.7
 445.6
 555.2
 691.7
 861.7
1073.5
1337.4
1666.1
2075.7
2585.9
3221.5
4013.4
5000.0
```

ARC - COAL AND HYDROCARBON PROCESSING DEPT.(SURFACE LABORATORY)

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1TK-0813
STION 5 STARTED 8/15/91 14:50 NITROGEN

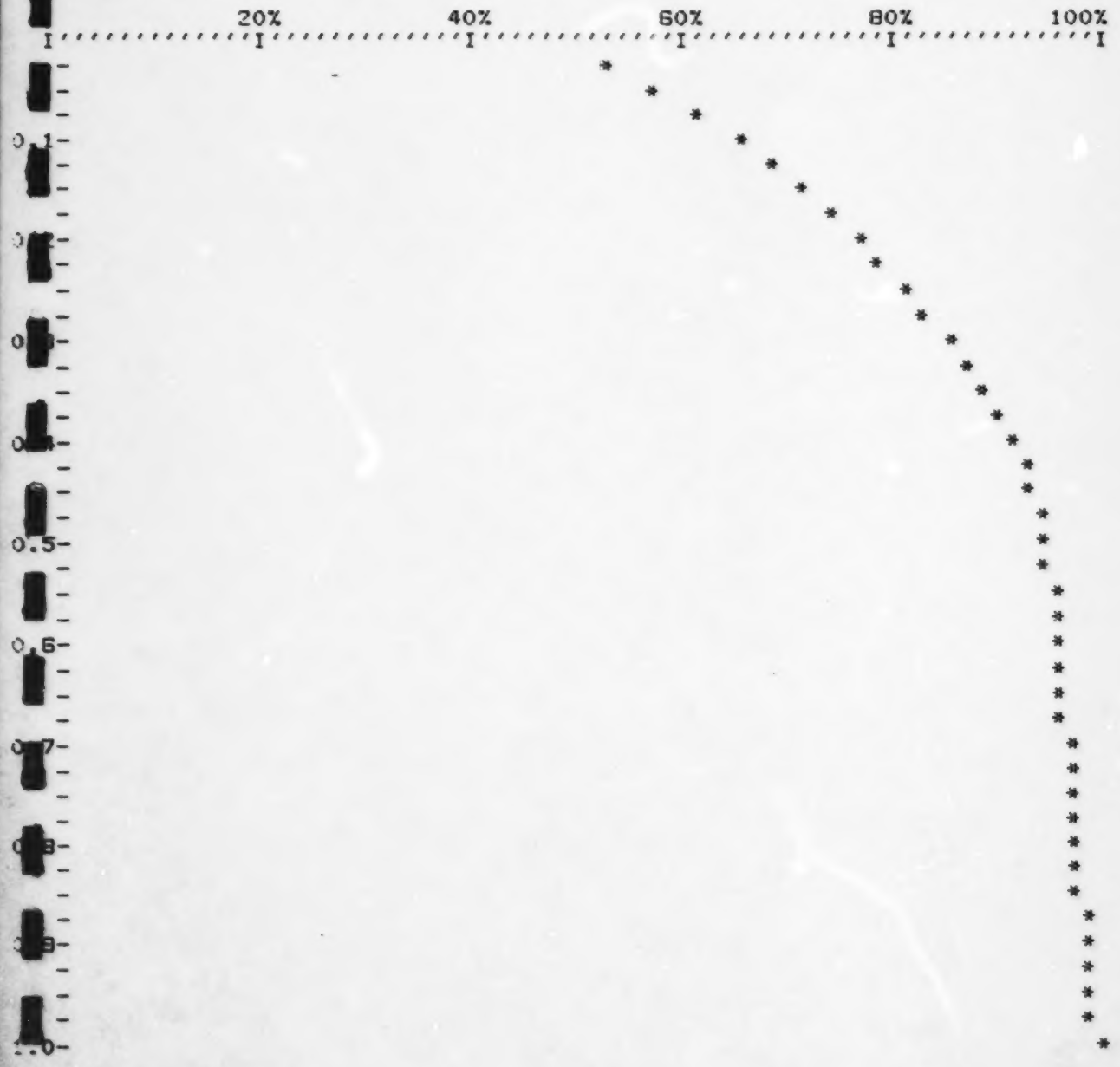
PRESSURE (MMHG)	VOL ADSORBED (CC STP/G)	ELAPSED TIME (HR:MN)	SATURATION PRESS (MMHG)	BET SURFACE AREA ESTIMATE (M2/G)
		0: 0	713.811	
0.039	48.7716	0:15		
0.594	97.6842	0:34		
		0:36	713.401	
19.107	146.5482	1: 0		
35.715	160.1004	1:16		
		1:18	712.459	
48.850	168.5959	1:32		
62.736	176.5944	1:42		
77.270	184.2862	1:53		
		1:56	713.901	
91.759	191.3502	2: 7		
106.402	198.0756	2:18		
121.017	204.4836	2:29		
		2:33	714.015	
136.008	210.5588	2:44		
151.228	216.3354	2:54		771.588
177.868	225.7927	3: 5		
		3: 7	713.473	
217.970	238.1060	3:19		
290.302	254.1292	3:31		
358.544	261.7925	3:39		
		3:41	713.015	
391.388	263.8639	3:49		
428.855	265.3700	3:54		
445.485	265.9096	3:58		
462.447	266.4402	4: 3		
497.216	267.6449	4: 7		
516.751	268.1786	4:11		
		4:15	713.684	
533.679	268.7638	4:20		
569.230	269.8338	4:25		
639.898	271.9690	4:31		
675.839	273.3345	4:35		
		4:38	713.826	
710.367	277.0746	4:46		
		4:48	713.564	

[illegible]-0813 NITROGEN
[illegible]TION 5 STARTED 8/15/91 14:50 COMPLETED 8/16/91 14:27

ISOTHERM PLOT

% OF MAXIMUM VOLUME VERSUS RELATIVE PRESSURE

[illegible]AX VOL SORBED = 277.0746 CC/G STP MAX VOL FOR PLOT = 277.0746 CC/G STP



1TK-0813 NITROGEN
STATION 5 STARTED 8/15/91 14:50 COMPLETED 8/16/91 14:27

ADSORPTION ISOTHERM

SAMPLE WEIGHT: 0.2699 G EQUILIBRATION INTERVAL: 10 SECS
FREE SPACE: 84.8513 CC MAX VOL INCREMENT: 50.000 CC/G STP

P/PO	VOL ADSORBED (CC/G AT STP)
0.000055	48.772
0.000833	97.684
0.02680	146.55
0.05013	160.10
0.06851	168.60
0.08794	176.59
0.1083	184.29
0.1285	191.35
0.1490	198.08
0.1695	204.48
0.1905	210.56
0.2119	216.34
0.2493	225.79
0.3056	238.11
0.4071	254.13
0.5028	261.79
0.5488	263.86
0.6013	265.37
0.6245	265.91
0.6482	266.44
0.6968	267.64
0.7241	268.18
0.7478	268.76
0.7975	269.83
0.8965	271.97
0.9468	273.33
0.9955	277.07

1TK-0813 NITROGEN
STATION 5 STARTED 8/15/91 14:50 COMPLETED 8/16/91 14:27

SPECIFIC SURFACE AREA

BET SURFACE AREA:	771.6729	+/-	1.9215 SQ M/G
SLOPE:	0.005589	+/-	0.000014
INTERCEPT:	0.000052	+/-	0.000002
C:	107.8544		
VM:	177.2657 CC		
CORRELATION COEFFICIENT	1.0000		

RELATIVE PRESSURE RANGE: 0.0500 TO 0.2100

:TK-0813 NITROGEN
:TION 5 STARTED 8/15/91 14:50 COMPLETED 8/16/91 14:27

ADSORPTION PORE VOLUME AND PORE AREA DISTRIBUTIONS

PORE DIA. RANGE, A	AVERAGE DIA.,A	PORE VOLUME (CC/G)	CUMULATIVE PORE VOLUME	PORE AREA (SQ M/G)	CUMULATIVE PORE AREA
233.7- 375.8	402.3	0.005422	0.005422	0.539	0.539
375.8- 201.5	236.4	0.002368	0.007790	0.401	0.940
201.5- 104.8	121.8	0.004083	0.011873	1.340	2.280
104.8- 80.7	87.7	0.002116	0.013989	0.965	3.245
80.7- 72.5	75.5	0.001193	0.015182	0.633	3.878
72.5- 65.6	68.4	0.001068	0.016251	0.624	4.502
65.6- 56.2	59.8	0.002563	0.018814	1.715	6.217
56.2- 51.7	53.3	0.001115	0.019928	0.837	7.054
51.7- 48.2	49.6	0.001151	0.021079	0.927	7.981
48.2- 42.1	44.5	0.003391	0.024470	3.046	11.027
42.1- 37.3	39.0	0.004975	0.029445	5.098	16.125
37.3- 30.1	32.5	0.019787	0.049231	24.321	40.446
30.1- 23.8	25.7	0.043741	0.092972	68.062	108.508
23.8- 20.4	21.4	0.033359	0.126331	62.455	170.964
20.4- 18.3	19.0	0.025132	0.151464	52.950	223.913
18.3- 17.2	17.5	0.014930	0.166394	34.060	257.973
17.2- 16.2	16.5	0.015495	0.181889	37.488	295.462
16.2- 15.2	15.6	0.016134	0.198023	41.471	336.933
15.2- 14.3	14.6	0.016372	0.214395	44.839	381.772
14.3- 13.3	13.6	0.016513	0.230909	48.415	430.186
13.3- 12.3	12.7	0.017139	0.248047	54.139	484.325
12.3- 11.3	11.7	0.016436	0.264483	56.403	540.728
11.3- 10.3	10.6	0.015637	0.280120	58.863	599.591
10.3- 8.9	9.3	0.021088	0.301208	90.440	690.031
8.9- 5.8	6.3	0.060658	0.361866	383.969	1074.000
5.8- 3.5	3.7	0.091627	0.453494	986.811	2060.811

LIQUID EQUIVALENT OF MAXIMUM VOLUME SORBED: 0.428579 CC/G

ITK-0813 NITROGEN
STATION 5 STARTED 8/15/91 14:50 COMPLETED 8/16/91 14:27

INCREMENTAL PORE VOLUME DISTRIBUTION (ADSORPTION)

% OF MAXIMUM PORE VOLUME VERSUS AVERAGE PORE DIAMETER, ANGSTROMS
MAX INC PORE VOLUME = 0.091627 CC/G MAX INC FOR PLOT = 0.091627 CC/G

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                20%          40%          60%          80%         100%
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 25.6 *********************************
 31.9 ****************
 39.7 ***
 49.5 *
 61.6 **
 76.8 *
 95.7 **
119.2 ***
148.5 ***
185.0 **
230.5 **
287.1 **
357.7 ***
445.6
555.2
691.7
861.7
1073.5
1337.4
1666.1
2075.7
2585.9
3221.5
4013.4
5000.0
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ATK-0813 NITROGEN
STATION 5 STARTED 8/15/91 14:50 COMPLETED 8/16/91 14:27

INCREMENTAL PORE AREA DISTRIBUTION (ADSORPTION)

% OF MAXIMUM PORE AREA VERSUS AVERAGE PORE DIAMETER, ANGSTROMS
MAX INC PORE AREA = 986.811 SQ M/G MAX INC FOR PLOT = 986.811 SQ M/G

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                20%          40%          60%          80%          100%
    I'''''''''''''I''''''''''''I''''''''''''I''''''''''''I''''''''''''I
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20.5 ****
25.6 ****
31.9 **
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61.6
76.8
95.7
119.2
148.5
185.0
230.5
287.1
357.7
445.6
555.2
691.7
861.7
1073.5
1337.4
1666.1
2075.7
2585.9
3221.5
4013.4
5000.0
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ARC - COAL AND HYDROCARBON PROCESSING DEPT.(SURFACE LABORATORY)

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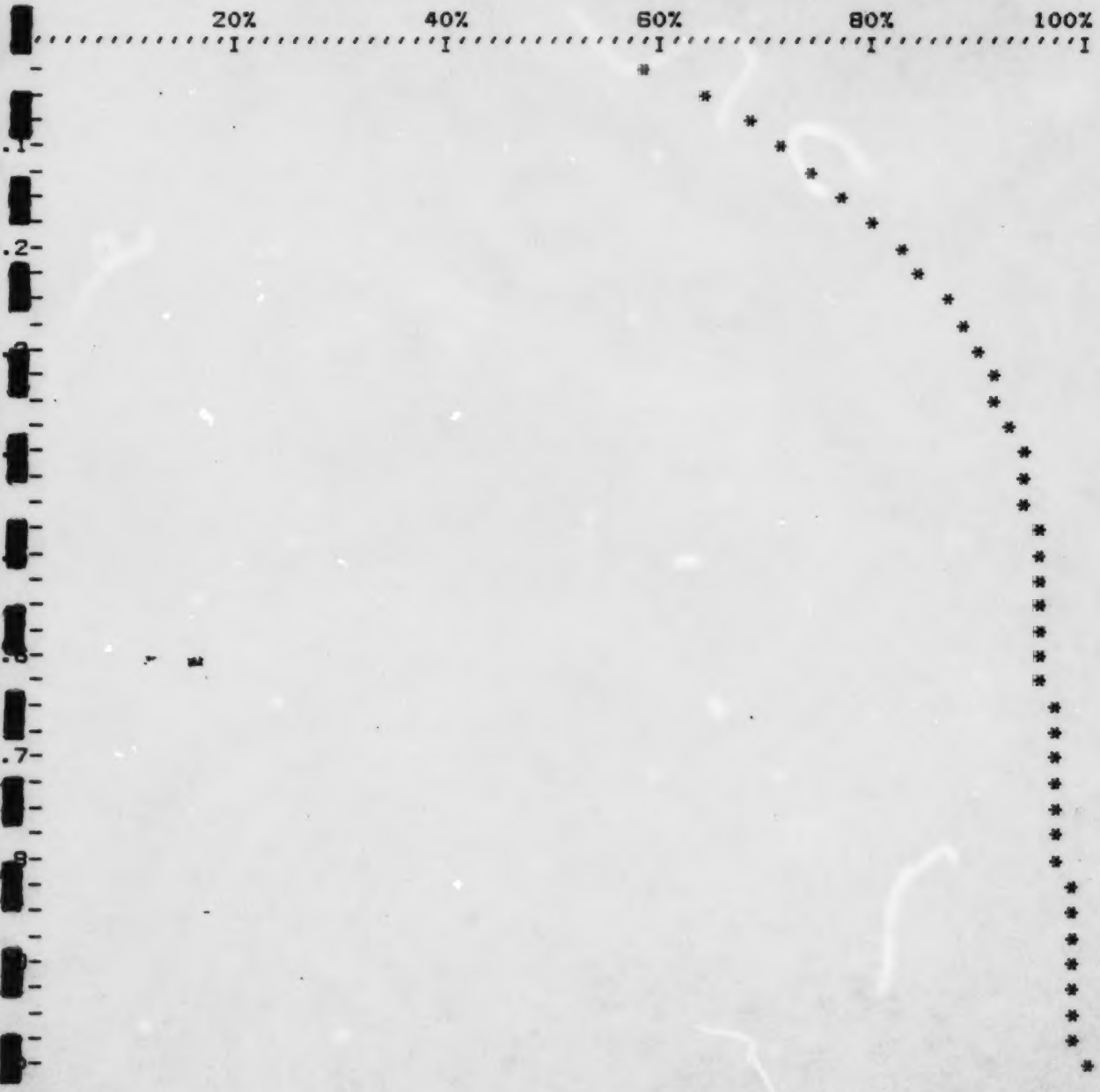
T 0822 NITROGEN
TATION 1 STARTED 10/28/91 15:48

PRESSURE (MMHG)	VOL ADSORBED (CC STP/G)	ELAPSED TIME (HR:MN)	SATURATION PRESS (MMHG)	BET SURFACE AREA ESTIMATE (M2/G)
		0: 0	736.456	
0.026	49.1213	0:15		
0.222	98.3847	0:36		
		0:38	736.014	
3.893	143.9026	1: 2		
35.795	186.4356	1:31		
		1:36	735.633	
50.889	197.0666	1:53		
65.755	206.1165	2: 4		
80.699	214.2141	2:13		
		2:17	734.052	
95.617	221.6402	2:28		
110.606	228.3699	2:37		
125.889	234.7126	2:46		
141.455	240.6387	2:55		
		2:57	734.049	
157.288	246.1481	3: 6		871.766
184.249	254.5979	3:16		
225.108	264.7387	3:26		
289.725	275.7054	3:34		
		3:36	733.370	
368.086	280.3803	3:44		
405.940	281.8130	3:49		
438.337	282.4974	3:54		
457.708	282.5832	3:58		
474.253	283.5245	4: 2		
512.867	284.5543	4: 6		
		4: 9	733.088	
530.488	284.8626	4:12		
548.216	285.5089	4:16		
585.169	286.4297	4:21		
659.433	288.4706	4:29		
695.211	289.7941	4:34		
		4:36	733.570	
730.162	293.0841	4:44		
		4:46	733.259	

TK-0822 NITROGEN
STATION 1 STARTED 10/28/91 15:48 COMPLETED 10/28/91 23:46

ISOTHERM PLOT

% OF MAXIMUM VOLUME VERSUS RELATIVE PRESSURE
AX VOL SORBED = 293.0841 CC/G STP MAX VOL FOR PLOT = 293.0841 CC/G STP



[redacted]-0822 NITROGEN
TATION 1 STARTED 10/28/91 15:48 COMPLETED 10/28/91 23:46

ADSORPTION ISOTHERM

[redacted]PLE WEIGHT: 0.2549 G EQUILIBRATION INTERVAL: 10 SECS
[redacted]EE SPACE: 83.5779 CC MAX VOL INCREMENT: 50.000 CC/G STP

P/PO	VOL ADSORBED (CC/G AT STP)
0.000035	49.121
0.000302	98.385
0.005291	143.90
0.04866	186.44
0.06924	197.07
0.08952	206.12
0.1099	214.21
0.1303	221.64
0.1507	228.37
0.1715	234.71
0.1927	240.64
0.2143	246.15
0.2511	254.60
0.3069	264.74
0.4087	275.71
0.4992	280.38
0.5536	281.81
0.5978	282.50
0.6243	282.58
0.6469	283.52
0.6996	284.55
0.7236	284.86
0.7477	285.51
0.7980	286.43
0.8991	288.47
0.9478	289.79
0.9957	293.08

TR-0822 NITROGEN
STATION 1 STARTED 10/28/91 15:48 COMPLETED 10/28/91 23:46

SPECIFIC SURFACE AREA

BET SURFACE AREA:	871.6781	+/-	4.2946 SQ M/G
SLOPE:	0.004962	+/-	0.000024
INTERCEPT:	0.000032	+/-	0.000003
C:	156.8272		
VM:	200.2385 CC		
CORRELATION COEFFICIENT	0.9999		

RELATIVE PRESSURE RANGE: 0.0500 TO 0.2100

-0822 NITROGEN
TATION 1 STARTED 10/28/91 15:48 COMPLETED 10/28/91 23:46

ADSORPTION PORE VOLUME AND PORE AREA DISTRIBUTIONS

PORE DIA. RANGE, A	AVERAGE DIA.,A	PORE VOLUME (CC/G)	CUMULATIVE PORE VOLUME	PORE AREA (SQ M/G)	CUMULATIVE PORE AREA
455.4- 382.5	408.6	0.004751	0.004751	0.465	0.465
382.5- 206.4	242.1	0.002308	0.007060	0.381	0.847
206.4- 105.1	122.3	0.003898	0.010957	1.274	2.121
105.1- 80.5	87.6	0.001797	0.012755	0.820	2.941
80.5- 72.3	75.2	0.001338	0.014093	0.711	3.652
72.3- 66.1	68.6	0.000572	0.014665	0.334	3.986
66.1- 55.9	59.8	0.002147	0.016812	1.437	5.423
55.9- 51.5	53.0	0.002146	0.018958	1.618	7.041
51.5- 42.5	44.5	0.001398	0.020355	1.256	8.297
42.5- 37.0	39.0	0.003310	0.023665	3.396	11.693
37.0- 30.1	32.4	0.011887	0.035553	14.681	26.374
30.1- 23.8	25.7	0.029747	0.065300	46.314	72.688
23.8- 20.4	21.3	0.027964	0.093263	52.405	125.093
20.4- 18.4	19.0	0.023118	0.116381	48.703	173.797
18.4- 17.2	17.5	0.014764	0.131145	33.666	207.463
17.2- 16.2	16.5	0.015734	0.146879	38.076	245.539
16.2- 15.2	15.5	0.016596	0.163474	42.702	288.241
15.2- 14.2	14.6	0.017211	0.180685	47.212	335.453
14.2- 13.3	13.6	0.018561	0.199246	54.506	389.959
13.3- 12.3	12.6	0.019325	0.218571	61.157	451.116
12.3- 11.3	11.6	0.020402	0.238974	70.259	521.375
11.3- 10.1	10.5	0.021861	0.260835	83.228	604.603
10.1- 7.1	7.8	0.067364	0.328198	346.114	950.717
7.1- 4.4	4.8	0.065439	0.393638	544.253	1494.970

LIQUID EQUIVALENT OF MAXIMUM VOLUME SORBED: 0.453342 CC/G

[redacted]-0822 NITROGEN
[redacted]TATION 1 STARTED 10/28/91 15:48 COMPLETED 10/28/91 23:46

INCREMENTAL PORE VOLUME DISTRIBUTION (ADSORPTION)

% OF MAXIMUM PORE VOLUME VERSUS AVERAGE PORE DIAMETER, ANGSTROMS
MAX INC PORE VOLUME = 0.067364 CC/G MAX INC FOR PLOT = 0.067364 CC/G

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              20%          40%          60%          80%          100%
   I'''''''''''I''''''''''''I''''''''''''I''''''''''''I''''''''''''I
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  4.4 ********************************************************************
  5.5 ********************************************************************
  6.8 ********************************************************************
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 20.5 ************************
 25.6 ******************************
 31.9 **************
 39.7 ***
 49.5
 61.6 **
 76.8 *
 95.7 **
[redacted]9.2 ****
148.5 ***
185.0 ***
230.5 **
287.1 ***
357.7 ****
445.6
555.2
691.7
861.7
1073.5
1337.4
1666.1
2075.7
2585.9
3221.5
4013.4
5000.0
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872 m²/g

0.4 cc/g

T[redacted]-0822 NITROGEN
TATION 1 STARTED 10/28/91 15:48 COMPLETED 10/28/91 23:46

INCREMENTAL PORE AREA DISTRIBUTION (ADSORPTION)

% OF MAXIMUM PORE AREA VERSUS AVERAGE PORE DIAMETER, ANGSTROMS
MAX INC PORE AREA = 544.253 SQ M/G MAX INC FOR PLOT = 544.253 SQ M/G

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                20%          40%          60%          80%          100%
   I''''''''''''I''''''''''''I''''''''''''I''''''''''''I''''''''''''I
  3.5 ************************************************************
  4.4 ************************************************************
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 185.0
 230.5
 287.1
 357.7
 445.6
 555.2
 691.7
 861.7
1073.5
1337.4
1666.1
2075.7
2585.9
3221.5
4013.4
5000.0
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972 m²/g
0.45 cc/g

ARC - COAL AND HYDROCARBON PROCESSING DEPT.(SURFACE LABORATORY)

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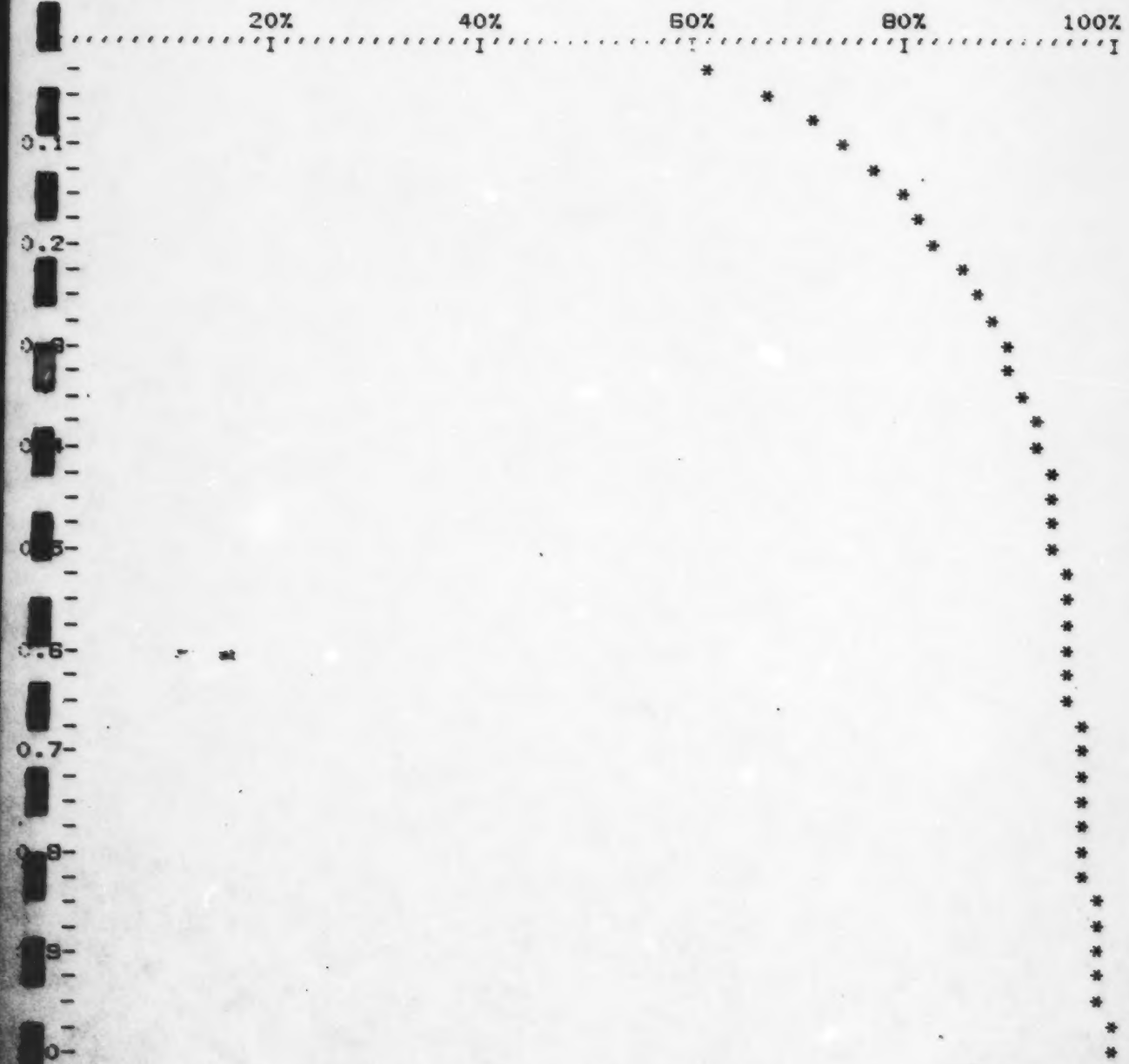
-0828 NITROGEN
TATION 2 STARTED 10/28/91 15:48

PRESSURE (MMHG)	VOL ADSORBED (CC STP/G)	ELAPSED TIME (HR:MN)	SATURATION PRESS (MMHG)	BET SURFACE AREA ESTIMATE (M2/G)
		0: 0	733.259	
0.067	49.7670	0: 9		
6.185	97.9537	0:44		
		0:46	732.643	
36.400	119.5905	1:11		
53.693	126.3037	1:20		
		1:22	732.072	
65.930	130.4019	1:36		
80.672	134.8276	1:45		
95.781	138.7152	1:53		
		1:55	732.013	
110.650	142.2987	2: 4		
125.712	145.6461	2:12		
141.277	148.6160	2:19		
156.381	151.4361	2:27		530.449
		2:29	731.500	
183.325	155.7306	2:38		
222.097	160.7260	2:46		
294.333	166.8719	2:53		
364.344	169.8587	2:59		
402.100	171.1872	3: 6		
		3: 8	731.082	
439.629	172.0399	3:12		
456.461	172.2865	3:16		
474.264	172.5988	3:20		
509.777	173.4736	3:25		
529.940	173.8105	3:29		
547.533	174.0287	3:33		
582.890	174.7212	3:37		
657.566	176.3072	3:45		
		3:47	731.674	
693.627	177.4528	3:52		
727.960	179.0195	3:56		
		3:58	732.037	

TR-0828 NITROGEN
STATION 2 STARTED 10/28/91 15:48 COMPLETED 10/29/91 3:55

ISOTHERM PLOT

% OF MAXIMUM VOLUME VERSUS RELATIVE PRESSURE
AX VOL SORBED = 179.0195 CC/G STP MAX VOL FOR PLOT = 179.0195 CC/G STP



-0828 NITROGEN
TATION 2 STARTED 10/28/91 15:48 COMPLETED 10/29/91 3:56

ADSORPTION ISOTHERM

PLE WEIGHT: 0.2517 G EQUILIBRATION INTERVAL: 10 SECS
EE SPACE: 86.7042 CC MAX VOL INCREMENT: 50.000 CC/G STP

P/PO	VOL ADSORBED (CC/G AT STP)
0.000091	49.767
0.008442	97.954
0.04971	119.59
0.07334	126.30
0.09006	130.40
0.1102	134.83
0.1308	138.72
0.1512	142.30
0.1718	145.65
0.1931	148.62
0.2138	151.44
0.2506	155.73
0.3037	160.73
0.4025	166.87
0.4983	169.86
0.5500	171.19
0.6013	172.04
0.6243	172.29
0.6485	172.60
0.6970	173.47
0.7246	173.81
0.7485	174.03
0.7968	174.72
0.8987	176.31
0.9478	177.45
0.9945	179.02

TX-0828
TATION 2 NITROGEN
STARTED 10/28/91 15:48 COMPLETED 10/29/91 3:56

SPECIFIC SURFACE AREA

BET SURFACE AREA:	530.3497	+/-	4.0534 SQ M/G
SLOPE:	0.008188	+/-	0.000062
INTERCEPT:	0.000020	+/-	0.000009
C:	416.6569		
VM:	121.8299 CC		
CORRELATION COEFFICIENT	0.9999		

RELATIVE PRESSURE RANGE: 0.0500 TO 0.2100

T -0828 NITROGEN
TATION 2 STARTED 10/28/91 15:48 COMPLETED 10/29/91 3:56

ADSORPTION PORE VOLUME AND PORE AREA DISTRIBUTIONS

PORE DIA. RANGE, A	AVERAGE DIA.,A	PORE VOLUME (CC/G)	CUMULATIVE PORE VOLUME	PORE AREA (SQ M/G)	CUMULATIVE PORE AREA
532.3- 383.5	415.9	0.002336	0.002336	0.225	0.225
383.5- 206.4	242.1	0.002076	0.004413	0.343	0.568
206.4- 105.2	122.3	0.003098	0.007511	1.013	1.581
105.2- 81.4	88.3	0.001382	0.008894	0.626	2.207
81.4- 73.2	76.2	0.000408	0.009302	0.214	2.422
73.2- 66.2	69.1	0.000685	0.009987	0.397	2.818
66.2- 56.8	60.4	0.001928	0.011915	1.277	4.095
56.8- 52.2	53.9	0.000654	0.012570	0.486	4.581
52.2- 48.8	50.2	0.000502	0.013071	0.400	4.981
48.8- 42.8	45.2	0.001947	0.015018	1.724	6.705
42.8- 37.5	39.4	0.003266	0.018284	3.314	10.019
37.5- 30.4	32.7	0.007676	0.025959	9.377	19.396
30.4- 24.3	26.1	0.017263	0.043223	26.478	45.874
24.3- 21.0	21.9	0.014319	0.057542	26.143	72.017
21.0- 19.0	19.6	0.012339	0.069881	25.154	97.171
19.0- 17.8	18.2	0.008094	0.077975	17.795	114.966
17.8- 16.8	17.2	0.008341	0.086316	19.392	134.358
16.8- 15.9	16.2	0.009509	0.095825	23.445	157.803
15.9- 14.9	15.3	0.010020	0.105845	26.252	184.055
14.9- 14.0	14.3	0.010544	0.116388	29.486	213.542
14.0- 13.0	13.3	0.011928	0.128316	35.822	249.363
13.0- 12.1	12.4	0.010583	0.138899	34.182	283.545
12.1- 10.9	11.3	0.016309	0.155209	57.643	341.188
10.9- 8.2	8.8	0.045635	0.200843	206.897	548.085
8.2- 5.0	5.4	0.099924	0.300768	738.482	1286.567

LIQUID EQUIVALENT OF MAXIMUM VOLUME SORBED: 0.276907 CC/G

TN 0826 NITROGEN
TATION 2 STARTED 10/28/91 15:48 COMPLETED 10/29/91 0:56

INCREMENTAL PORE VOLUME DISTRIBUTION (ADSORPTION)

% OF MAXIMUM PORE VOLUME VERSUS AVERAGE PORE DIAMETER, ANGSTROMS
MAX INC PORE VOLUME = 0.099924 CC/G MAX INC FOR PLOT = 0.099924 CC/G

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              20%          40%          60%          80%          100%
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287.1 *
357.7 *
435.6
555.2
691.7
851.7
 0.3.5
337.4
 6.1
 5.7
585.9
221.5
 0.3.4
 0.0.0
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-0828 NITROGEN
TATION 2 STARTED 10/28/91 15:48 COMPLETED 10/29/91 3:56

INCREMENTAL PORE AREA DISTRIBUTION (ADSORPTION)

% OF MAXIMUM PORE AREA VERSUS AVERAGE PORE DIAMETER, ANGSTROMS
MAX INC PORE AREA = 738.482 SQ M/G MAX INC FOR PLOT = 738.482 SQ M/G

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              20%          40%          60%          80%         100%
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119.2
148.5
185.0
230.5
287.1
357.7
445.6
555.2
691.7
861.7
1073.5
1337.4
1666.1
2075.7
2585.9
3221.5
4013.4
5000.0
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ARC - COAL AND HYDROCARBON PROCESSING DEPT.(SURFACE LABORATORY)

'DIGISORB 2600 V3.03 PAGE 1
105

-1016 NITROGEN
'TATION 3 STARTED 10/28/91 15:48

PRESSURE (MMHG)	VOL ADSORBED (CC STP/G)	ELAPSED TIME (HR:MN)	SATURATION PRESS (MMHG)	BET SURFACE AREA ESTIMATE (M2/G)
		0: 0	732.037	
0.022	49.0096	0:16		
0.072	98.2062	0:38		
		0:40	731.686	
0.433	147.4819	1: 3		
4.255	196.0430	1:23		
		1:25	731.116	
26.671	244.2366	1:50		
36.440	256.3824	2: 6		
		2: 8	730.869	
51.417	272.2428	2:26		
64.577	284.5453	2:39		
		2:42	730.556	
79.767	297.3405	2:57		
92.610	307.2315	3: 7		
107.780	317.9328	3:17		
		3:20	730.272	
123.041	327.9815	3:31		
138.710	337.0993	3:42		
154.040	345.3194	3:52		1239.477
		3:54	730.582	
183.320	358.5905	4: 5		
228.180	373.4290	4:15		
297.614	384.9717	4:25		
		4:26	730.510	
363.452	389.6273	4:34		
408.469	391.6411	4:40		
438.256	392.7315	4:45		
455.373	393.3802	4:49		
474.450	394.0334	4:54		
508.430	395.3914	4:59		
		5: 1	730.289	
529.373	396.1353	5: 5		
547.533	396.8330	5:10		
582.203	397.7987	5:14		
656.427	400.6649	5:22		
693.874	402.6564	5:28		
		5:30	731.176	
728.166	406.5816	5:39		
		5:41	731.135	

TX-1016
STATION 3 STARTED 10/28/91 15:48 COMPLETED 10/29/91 9:47 NITROGEN

ISOTHERM PLOT

% OF MAXIMUM VOLUME VERSUS RELATIVE PRESSURE
MAX VOL SORBED = 406.5817 CC/G STP MAX VOL FOR PLOT = 406.5817 CC/G STP

-1016 NITROGEN
TATION 3 STARTED 10/28/91 15:48 COMPLETED 10/29/91 9:47

ADSORPTION ISOTHERM

PLE WEIGHT: 0.2650 G EQUILIBRATION INTERVAL: 10 SECS
E SPACE: 88.5546 CC MAX VOL INCREMENT: 50.000 CC/G STP

P/PO	VOL ADSORBED (CC/G AT STP)
0.000030	49.010
0.000099	98.206
0.000592	147.48
0.005820	196.04
0.03649	244.24
0.04986	256.38
0.07037	272.24
0.08839	284.55
0.1092	297.34
0.1268	307.23
0.1476	317.93
0.1685	327.98
0.1899	337.10
0.2109	345.32
0.2509	358.59
0.3137	373.43
0.4074	384.97
0.4976	389.63
0.5592	391.64
0.6000	392.73
0.6235	393.38
0.6496	394.03
0.6976	395.39
0.7248	396.14
0.7495	396.63
0.7968	397.80
0.8981	400.66
0.9491	402.66
0.9959	406.58

TW-1016 NITROGEN
TATION 3 STARTED 10/28/91 15:48 COMPLETED 10/29/91 8:47

SPECIFIC SURFACE AREA

BET SURFACE AREA:	1239.5121	+/-	4.7281 SQ M/G
SLOPE:	0.003480	+/-	0.000013
INTERCEPT:	0.000032	+/-	0.000002
C:	108.1477		
VM:	284.7359 CC		
CORRELATION COEFFICIENT	1.0000		

RELATIVE PRESSURE RANGE: 0.0500 TO 0.2100

-1016 NITROGEN
TATION 3 STARTED 10/28/91 15:48 COMPLETED 10/29/91 9:47

ADSORPTION PORE VOLUME AND PORE AREA DISTRIBUTIONS

PORE DIA. RANGE, A	AVERAGE DIA.,A	PORE VOLUME (CC/G)	CUMULATIVE PORE VOLUME	PORE AREA (SQ M/G)	CUMULATIVE PORE AREA
711.3- 392.0	418.1	0.005649	0.005649	0.540	0.540
392.0- 204.5	240.4	0.003517	0.009167	0.585	1.126
204.5- 104.3	121.3	0.005487	0.014654	1.809	2.935
104.3- 80.8	87.6	0.002256	0.016910	1.030	3.964
80.8- 72.4	75.5	0.000947	0.017857	0.502	4.466
72.4- 65.5	68.3	0.001513	0.019370	0.886	5.352
65.5- 56.1	59.7	0.002840	0.022209	1.903	7.256
56.1- 51.3	53.0	0.001344	0.023553	1.014	8.270
51.3- 47.8	49.1	0.001369	0.024923	1.114	9.384
47.8- 42.8	44.8	0.002320	0.027243	2.072	11.456
42.8- 36.7	39.0	0.004518	0.031761	4.639	16.095
36.7- 29.8	32.1	0.011327	0.043088	14.134	30.229
29.8- 23.9	25.7	0.030722	0.073810	47.858	78.087
23.9- 20.2	21.3	0.040735	0.114545	76.499	154.586
20.2- 18.0	18.7	0.036301	0.150846	77.713	232.299
18.0- 16.8	17.2	0.022125	0.172971	51.534	283.833
16.8- 15.8	16.2	0.024176	0.197147	59.785	343.618
15.8- 14.8	15.2	0.026392	0.223539	69.517	413.136
14.8- 13.9	14.2	0.027252	0.250791	76.700	489.836
13.9- 13.0	13.3	0.024400	0.275191	73.404	563.240
13.0- 12.0	12.4	0.030325	0.305516	97.991	661.230
12.0- 11.1	11.4	0.027335	0.332851	95.979	757.210
11.1- 10.0	10.4	0.032075	0.364926	123.890	881.100
10.0- 9.0	9.3	0.021372	0.386298	91.770	972.870
9.0- 6.7	7.3	0.063289	0.449587	345.819	1318.689
6.7- 4.5	4.8	0.056730	0.506316	468.951	1787.640

LIQUID EQUIVALENT OF MAXIMUM VOLUME SORBED: 0.628901 CC/G

[redacted]-1016 NITROGEN
[redacted]TATION 3 STARTED 10/28/91 15:48 COMPLETED 10/29/91 9:47

INCREMENTAL PORE VOLUME DISTRIBUTION (ADSORPTION)

% OF MAXIMUM PORE VOLUME VERSUS AVERAGE PORE DIAMETER, ANGSTROMS
MAX INC PORE VOLUME = 0.063289 CC/G MAX INC FOR PLOT = 0.063289 CC/G

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                20%          40%          60%          80%          100%
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 76.8 *
 95.7 ***
119.2 *****
148.5 *****
185.0 ****
230.5 ****
287.1 ****
357.7 *****
445.6
555.2
691.7
861.7
1073.5
1337.4
1666.1
2075.7
2585.9
3221.5
4013.4
5000.0
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$123\ m^2/g$

$0.63\ cc/g$

T[illegible]1016 NITROGEN
TATION 3 STARTED 10/28/91 15:48 COMPLETED 10/29/91 9:47

INCREMENTAL PORE AREA DISTRIBUTION (ADSORPTION)

% OF MAXIMUM PORE AREA VERSUS AVERAGE PORE DIAMETER, ANGSTROMS
MAX INC PORE AREA = 468.951 SQ M/G MAX INC FOR PLOT = 468.951 SQ M/G

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                20%          40%          60%          80%          100%
  I'''''''''''''I''''''''''''I''''''''''''I''''''''''''I''''''''''''I
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445.6
555.2
691.7
861.7
1073.5
1337.4
1666.1
2075.7
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4013.4
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1234 - 1/2

D. adj

ARC - COAL AND HYDROCARBON PROCESSING DEPT.(SURFACE LABORATORY)

DIGISORB 2600 V3.03 PAGE 1
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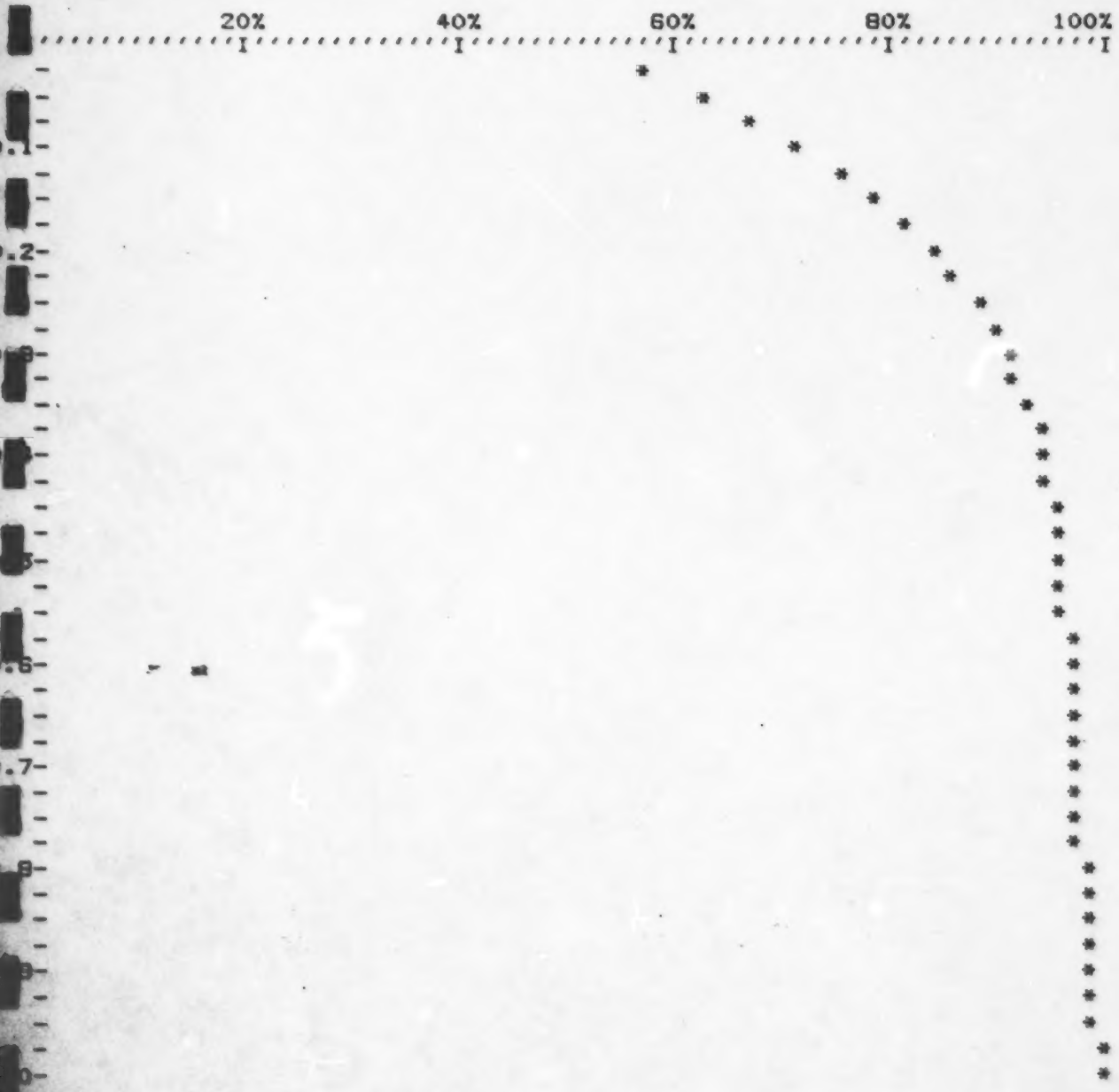
T-1018 NITROGEN
TATION 4 STARTED 10/28/91 15:48

PRESSURE (MMHG)	VOL ADSORBED (CC STP/G)	ELAPSED TIME (HR:MN)	SATURATION PRESS (MMHG)	BET SURFACE AREA ESTIMATE (M2/G)
		0: 0	731.135	
0.021	49.3421	0:17		
0.073	98.5809	0:42		
		0:46	731.187	
0.411	145.1644	1: 5		
3.511	191.0386	1:27		
		1:31	730.182	
22.465	237.3684	1:50		
36.514	255.5366	2: 7		
		2: 9	729.831	
49.930	268.9032	2:24		
64.688	283.9644	2:37		
77.928	295.3129	2:48		
		2:50	729.121	
93.077	307.1371	3: 0		
108.418	318.0389	3:11		
123.577	328.1359	3:22		
		3:24	729.032	
139.195	337.3200	3:35		
154.600	345.4624	3:44		1238.355
183.276	358.6051	3:54		
		3:57	728.700	
227.625	373.2291	4: 6		
296.801	385.1846	4:14		
362.958	389.8029	4:22		
406.421	391.9269	4:27		
		4:29	728.421	
437.244	393.0766	4:34		
454.255	393.6253	4:38		
472.830	394.3018	4:42		
508.296	395.6615	4:47		
527.640	396.3455	4:51		
545.583	397.1324	4:55		
581.240	398.3792	5: 0		
		5: 2	728.582	
654.959	401.4415	5:10		
692.555	403.3081	5:15		
		5:18	728.388	
722.985	406.8559	5:23		
		5:26	728.737	

TK-1018 NITROGEN
STATION 4 STARTED 10/28/91 15:48 COMPLETED 10/29/91 15:24

ISOTHERM PLOT

% OF MAXIMUM VOLUME VERSUS RELATIVE PRESSURE
MAX VOL SORBED = 406.8559 CC/G STP MAX VOL FOR PLOT = 406.8559 CC/G STP



-1018 NITROGEN
TATION 4 STARTED 10/28/91 15:48 COMPLETED 10/29/91 15:24

ADSORPTION ISOTHERM

PLE WEIGHT: 0.2344 G EQUILIBRATION INTERVAL: 10 SECS
E SPACE: 87.8257 CC MAX VOL INCREMENT: 50.000 CC/G STP

P/PO	VOL ADSORBED (CC/G AT STP)
0.000028	49.342
0.000100	98.581
0.000563	145.16
0.004808	191.04
0.03077	237.37
0.05003	255.54
0.06844	269.90
0.08869	283.96
0.1069	295.31
0.1277	307.14
0.1487	318.04
0.1695	328.14
0.1910	337.32
0.2121	345.46
0.2515	358.61
0.3124	373.23
0.4074	385.18
0.4982	389.80
0.5579	391.93
0.6002	393.08
0.6236	393.63
0.6491	394.30
0.6977	395.66
0.7243	396.35
0.7489	397.13
0.7978	398.38
0.8991	401.44
0.9508	403.31
0.9922	406.86

T 1018 NITROGEN
TATION 4 STARTED 10/28/91 15:48 COMPLETED 10/29/91 15:24

SPECIFIC SURFACE AREA

BET SURFACE AREA:	1238.2114	+/-	3.6440 SQ M/G
SLOPE:	0.003483	+/-	0.000010
INTERCEPT:	0.000033	+/-	0.000001
C:	107.4184		
VM:	284.4371 CC		
CORRELATION COEFFICIENT	1.0000		

RELATIVE PRESSURE RANGE: 0.0500 TO 0.2100

T 1018 NITROGEN
TATION 4 STARTED 10/28/91 15:48 COMPLETED 10/29/91 15:24

ADSORPTION PORE VOLUME AND PORE AREA DISTRIBUTIONS

PORE DIA. RANGE, A	AVERAGE DIA.,A	PORE VOLUME (CC/G)	CUMULATIVE PORE VOLUME	PORE AREA (SQ M/G)	CUMULATIVE PORE AREA
489.3- 405.1	453.2	0.005504	0.005504	0.486	0.486
405.1- 206.8	243.3	0.003292	0.008796	0.541	1.027
206.8- 104.8	122.0	0.005917	0.014714	1.940	2.967
104.8- 80.7	87.7	0.002421	0.017135	1.104	4.071
80.7- 72.3	75.3	0.001596	0.018730	0.847	4.918
72.3- 65.5	68.3	0.001364	0.020094	0.799	5.717
65.5- 56.0	59.7	0.002817	0.022911	1.889	7.606
56.0- 51.3	53.0	0.001397	0.024308	1.055	8.661
51.3- 47.8	49.2	0.001114	0.025423	0.906	9.567
47.8- 42.7	44.8	0.002448	0.027871	2.188	11.755
42.7- 36.8	39.0	0.004817	0.032688	4.947	16.702
36.8- 29.8	32.1	0.011179	0.043867	13.929	30.630
29.8- 23.8	25.7	0.031906	0.075773	49.745	80.376
23.8- 20.2	21.3	0.040211	0.115984	75.496	155.872
20.2- 18.1	18.8	0.036030	0.152015	76.855	232.726
18.1- 16.9	17.3	0.021879	0.173894	50.726	283.452
16.9- 15.9	16.2	0.024456	0.198350	60.204	343.656
15.9- 14.9	15.3	0.026657	0.225007	69.876	413.532
14.9- 13.9	14.3	0.027907	0.252914	78.151	491.684
13.9- 13.0	13.3	0.029298	0.282212	88.146	579.830
13.0- 12.0	12.3	0.026869	0.309081	87.067	666.897
12.0- 11.0	11.4	0.031391	0.340472	110.338	777.236
11.0- 10.0	10.3	0.028794	0.369266	111.552	888.787
10.0- 8.8	9.2	0.031265	0.400531	136.401	1025.188
8.8- 6.5	7.0	0.056669	0.457200	321.795	1346.983
6.5- 4.4	4.7	0.055358	0.512558	467.487	1814.470

LIQUID EQUIVALENT OF MAXIMUM VOLUME SORBED: 0.629325 CC/G

ITR-1018 NITROGEN
STATION 4 STARTED 10/28/91 15:48 COMPLETED 10/29/91 15:24

INCREMENTAL PORE VOLUME DISTRIBUTION (ADSORPTION)

% OF MAXIMUM PORE VOLUME VERSUS AVERAGE PORE DIAMETER, ANGSTROMS
MAX INC PORE VOLUME = 0.056669 CC/G MAX INC FOR PLOT = 0.056669 CC/G

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                20%          40%          60%          80%          100%
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 13.2 ************************************
 16.5 ****************************
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 39.7 *****
 49.5 *
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 76.8 **
 95.7 ****
119.2 *******
148.5 ******
185.0 *****
230.5 ****
287.1 ****
357.7 *****
445.6 ******
555.2
691.7
861.7
1073.5
1337.4
1666.1
2075.7
2585.9
3221.5
4013.4
5000.0
```

-1018 NITROGEN
TATION 4 STARTED 10/28/91 15:48 COMPLETED 10/29/91 15:24

INCREMENTAL PORE AREA DISTRIBUTION (ADSORPTION)

% OF MAXIMUM PORE AREA VERSUS AVERAGE PORE DIAMETER, ANGSTROMS
MAX INC PORE AREA = 467.487 SQ M/G MAX INC FOR PLOT = 467.487 SQ M/G

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                20%          40%          60%          80%          100%
    I'''''''''''I''''''''''''I''''''''''''I''''''''''''I''''''''''''I
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185.0
230.5
287.1
357.7
445.6
555.2
691.7
861.7
1073.5
1337.4
1666.1
2075.7
2585.9
3221.5
4013.4
5000.0
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1238 m²/g
0.67 cc/g

ARC - COAL AND HYDROCARBON PROCESSING DEPT.(SURFACE LABORATORY)

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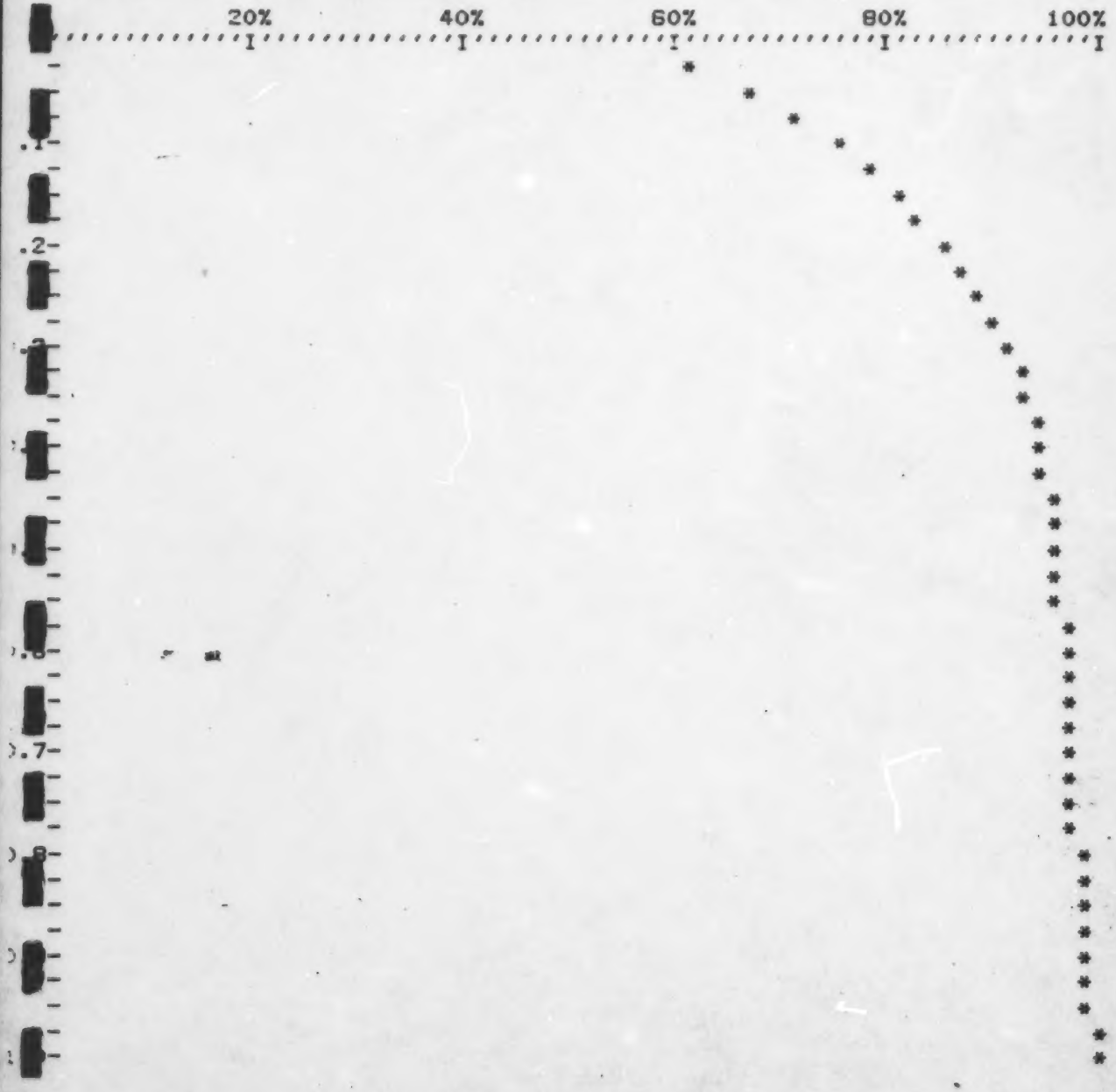
T 1023 NITROGEN
TATION 5 STARTED 10/28/91 15:48

PRESSURE (MMHG)	VOL ADSORBED (CC STP/G)	ELAPSED TIME (HR:MN)	SATURATION PRESS (MMHG)	BET SURFACE AREA ESTIMATE (M2/G)
		0: 0	728.737	
0.019	49.2184	0:13		
0.166	97.4023	0:29		
		0:32	728.035	
3.423	146.1002	1: 0		
35.721	191.3901	1:25		
		1:29	727.866	
50.735	201.8606	1:41		
64.590	210.1219	1:53		
79.570	217.8826	2: 3		
		2: 7	728.163	
94.797	225.0982	2:18		
110.142	231.3620	2:27		
125.467	237.1373	2:36		
140.856	242.4334	2:45		
		2:47	727.691	
156.968	247.0368	2:56		870.120
183.782	253.7551	3: 5		
222.321	261.4106	3:12		
284.896	270.0924	3:19		
		3:21	727.794	
361.485	273.5298	3:27		
397.407	274.6987	3:31		
433.865	276.3547	3:36		
455.745	276.6774	3:40		
472.338	276.9098	3:44		
507.245	278.1131	3:48		
527.995	278.6011	3:53		
		3:55	727.219	
544.863	279.0231	3:59		
580.613	279.7351	4: 3		
653.985	281.8546	4:11		
690.120	283.2067	4:16		
		4:19	727.317	
722.766	285.5258	4:24		
		4:26	727.512	

TX-1023 NITROGEN
TATION 5 STARTED 10/28/91 15:48 COMPLETED 10/29/91 20: 2

ISOTHERM PLOT

% OF MAXIMUM VOLUME VERSUS RELATIVE PRESSURE
AV VOL SORBED = 285.5258 CC/G STP MAX VOL FOR PLOT = 285.5258 CC/G STP



-1023 NITROGEN
TATION 5 STARTED 10/28/91 15:48 COMPLETED 10/29/91 20: 2

ADSORPTION ISOTHERM

PLE WEIGHT: 0.2308 G EQUILIBRATION INTERVAL: 10 SECS
E SPACE: 91.5834 CC MAX VOL INCREMENT: 50.000 CC/G STP

P/PO	VOL ADSORBED (CC/G AT STP)
0.000026	49.218
0.000228	97.402
0.004703	146.10
0.04908	191.39
0.06969	201.86
0.08872	210.12
0.1093	217.88
0.1302	225.10
0.1513	231.36
0.1724	237.14
0.1936	242.43
0.2157	247.04
0.2525	253.76
0.3055	261.41
0.4053	270.09
0.4967	273.53
0.5462	274.70
0.5963	276.35
0.6265	276.68
0.6493	276.91
0.6974	278.11
0.7260	278.60
0.7492	279.02
0.7984	279.74
0.8992	281.85
0.9489	283.21
0.9936	285.53

-R-1023
TATION 5 NITROGEN
STARTED 10/28/91 15:48 COMPLETED 10/29/91 20: 2

SPECIFIC SURFACE AREA

BET SURFACE AREA:	870.1135	+/-	6.1354 SQ M/G
SLOPE:	0.004983	+/-	0.000035
INTERCEPT:	0.000020	+/-	0.000005
C:	247.4464		
VM:	199.8791 CC		
CORRELATION COEFFICIENT	0.9999		

RELATIVE PRESSURE RANGE: 0.0500 TO 0.2100

1[illegible]-1023 NITROGEN
STATION 5 STARTED 10/28/91 15:48 COMPLETED 10/29/91 20: 2

ADSORPTION PORE VOLUME AND PORE AREA DISTRIBUTIONS

PORE DIA. RANGE, A	AVERAGE DIA.,A	PORE VOLUME (CC/G)	CUMULATIVE PORE VOLUME	PORE AREA (SQ M/G)	CUMULATIVE PORE AREA
995.4- 390.6	429.3	0.003520	0.003520	0.328	0.328
390.6- 206.9	242.9	0.002409	0.005929	0.397	0.725
206.9- 105.4	122.6	0.004106	0.010034	1.339	2.064
105.4- 81.1	88.1	0.001351	0.011385	0.613	2.677
81.1- 73.0	75.9	0.000845	0.012230	0.445	3.123
73.0- 65.7	68.7	0.000984	0.013215	0.573	3.696
65.7- 56.3	59.9	0.002610	0.015824	1.743	5.439
56.3- 51.9	53.5	0.000411	0.016235	0.307	5.746
51.9- 47.6	49.4	0.000597	0.016832	0.484	6.230
47.6- 41.7	44.0	0.003892	0.020724	3.538	9.768
41.7- 36.7	38.5	0.002613	0.023338	2.713	12.480
36.7- 29.9	32.2	0.008452	0.031789	10.501	22.981
29.9- 23.7	25.6	0.023510	0.055300	36.741	59.722
23.7- 20.4	21.4	0.021110	0.076410	39.486	99.208
20.4- 18.5	19.1	0.018441	0.094851	38.629	137.836
18.5- 17.3	17.6	0.012457	0.107308	28.253	166.089
17.3- 16.3	16.6	0.014497	0.121804	34.911	201.000
16.3- 15.3	15.6	0.015586	0.137390	38.907	240.907
15.3- 14.3	14.6	0.016514	0.153904	45.127	286.033
14.3- 13.3	13.6	0.018850	0.172753	55.248	341.281
13.3- 12.3	12.6	0.019379	0.192132	61.300	402.581
12.3- 11.3	11.6	0.019763	0.211895	67.895	470.476
11.3- 10.2	10.6	0.023249	0.235143	87.963	558.440
10.2- 7.1	7.8	0.079931	0.315075	412.430	970.870
7.1- 4.3	4.7	0.073095	0.388170	620.374	1591.244

LIQUID EQUIVALENT OF MAXIMUM VOLUME SORBED: 0.441651 CC/G

T[illegible]-1023 NITROGEN
TATION 5 STARTED 10/28/91 15:48 COMPLETED 10/29/91 20: 2

INCREMENTAL PORE VOLUME DISTRIBUTION (ADSORPTION)

% OF MAXIMUM PORE VOLUME VERSUS AVERAGE PORE DIAMETER, ANGSTROMS
MAX INC PORE VOLUME = 0.079931 CC/G MAX INC FOR PLOT = 0.079931 CC/G

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              20%          40%          60%          80%          100%
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 148.5 ***
 185.0 ***
 230.5 **
 287.1 **
 357.7 ***
 445.6
 555.2
 691.7
 861.7
1073.5
1337.4
1666.1
2075.7
2585.9
3221.5
4013.4
5000.0
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T 1023 NITROGEN
TATION 5 STARTED 10/28/91 15:48 COMPLETED 10/29/91 20: 2

INCREMENTAL PORE AREA DISTRIBUTION (ADSORPTION)

% OF MAXIMUM PORE AREA VERSUS AVERAGE PORE DIAMETER, ANGSTROMS
MAX INC PORE AREA = 620.374 SQ M/G MAX INC FOR PLOT = 620.374 SQ M/G

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                20%          40%          60%          80%          100%
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18.5 ****
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31.9 *
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95.7
119.2
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185.0
230.5
287.1
357.7
445.6
555.2
691.7
861.7
1073.5
1337.4
1666.1
2075.7
2585.9
3221.5
4013.4
5000.0
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ARC - COAL AND HYDROCARBON PROCESSING DEPT.(SURFACE LABORATORY)

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ULTRASORB300 , EDMONTON
STATION 2 STARTED 12/ 2/91 16:18 NITROGEN

PRESSURE (MMHG)	VOL ADSORBED (CC STP/G)	ELAPSED TIME (HR:MN)	SATURATION PRESS (MMHG)	BET SURFACE AREA ESTIMATE (M2/G)
		0: 0	725.302	
0.008	49.6922	0:18		
0.028	99.4459	0:34		
		0:38	724.120	
0.155	145.9805	0:57		
2.038	194.6554	1:19		
		1:21	723.728	
20.002	240.2539	1:47		
36.274	255.7687	2:10		
		2:13	722.864	
49.336	264.2600	2:29		
64.394	271.6523	2:40		
80.962	277.9067	2:52		
		2:54	722.633	
96.901	282.6557	3: 6		
112.209	286.4298	3:16		
127.491	289.5866	3:25		
		3:28	721.847	
142.086	292.2117	3:36		
156.554	294.5433	3:45		1018.244
181.527	298.0656	3:53		
218.403	302.5703	4: 2		
		4: 4	722.099	
286.816	309.8002	4:12		
359.701	316.6936	4:22		
395.990	319.9715	4:29		
431.832	323.3928	4:38		
		4:39	721.465	
451.380	325.1033	4:46		
468.059	326.7337	4:53		
504.831	330.7034	5: 6		
523.890	332.8293	5:14		
		5:16	720.870	
540.665	334.3897	5:22		
574.660	338.3315	5:30		
553.016	351.6326	5:44		
383.470	362.5627	5:57		
		6: 1	721.607	
718.243	385.1230	6:30		
		6:32	721.489	

RASORB300 , EDMONTON NITROGEN
ATION 2 STARTED 12/ 2/91 16:18 COMPLETED 12/ 3/91 6:55

ISOTHERM PLOT

% OF MAXIMUM VOLUME VERSUS RELATIVE PRESSURE
AX VOL SORBED = 385.1230 CC/G STP MAX VOL FOR PLOT = 385.1230 CC/G STP

ULTRASORB300 , EDMONTON NITROGEN
STATION 2 STARTED 12/ 2/91 16:18 COMPLETED 12/ 3/91 6:55

ADSORPTION ISOTHERM

SAMPLE WEIGHT: 0.3267 G EQUILIBRATION INTERVAL: 10 SECS
FREE SPACE: 85.2838 CC MAX VOL INCREMENT: 50.000 CC/G STP

P/PO	VOL ADSORBED (CC/G AT STP)
0.000011	49.692
0.000039	99.446
0.000214	145.98
0.002816	194.66
0.02765	240.25
0.05018	255.77
0.06826	264.26
0.08910	271.65
0.1120	277.91
0.1341	282.66
0.1554	286.43
0.1766	289.59
0.1968	292.21
0.2168	294.54
0.2514	298.07
0.3025	302.57
0.3973	309.80
0.4984	316.69
0.5487	319.97
0.5985	323.39
0.6257	325.10
0.6490	326.73
0.7001	330.70
0.7257	332.63
0.7499	334.39
0.7969	338.33
0.8953	351.63
0.9472	362.56
0.9827	385.12

ULTRASORB300 , EDMONTON NITROGEN
STATION 2 STARTED 12/ 2/91 16:19 COMPLETED 12/ 3/91 6:55

SPECIFIC SURFACE AREA

BET SURFACE AREA:	1018.2567	+/-	15.2463 SQ M/G
SLOPE:	0.004294	+/-	0.000063
INTERCEPT:	-0.000019	+/-	0.000008
C:	-225.7010		
VM:	233.9100 CC		
CORRELATION COEFFICIENT	0.9993		

LANGMUIR SURFACE AREA:	1339.7368	+/-	7.1092 SQ M/G
SLOPE:	0.003249	+/-	0.000017
INTERCEPT:	0.000037	+/-	0.000002
A*PO:	88.5413		
VM:	307.7592 CC		
CORRELATION COEFFICIENT	0.9999		

RELATIVE PRESSURE RANGE: 0.0500 TO 0.2100

ULTRASORB300 , EDMONTON
STATION 2 STARTED 12/ 2/91 16:18 COMPLETED 12/ 3/91 6:55 NITROGEN

ADSORPTION PORE VOLUME AND PORE AREA DISTRIBUTIONS

PORE DIA. RANGE, A	AVERAGE DIA.,A	PORE VOLUME (CC/G)	CUMULATIVE PORE VOLUME	PORE AREA (SQ M/G)	CUMULATIVE PORE AREA
646.2- 378.5	418.7	0.034533	0.034533	3.299	3.299
378.5- 218.6	255.2	0.019278	0.053811	3.022	6.321
218.6- 105.1	122.5	0.024824	0.078635	8.108	14.428
105.1- 81.1	87.9	0.007213	0.085848	3.281	17.710
81.1- 73.1	76.0	0.003236	0.089084	1.703	19.413
73.1- 66.2	69.0	0.003592	0.092676	2.082	21.495
66.2- 56.2	60.0	0.007813	0.100489	5.209	26.704
56.2- 51.7	53.3	0.003171	0.103660	2.381	29.085
51.7- 47.8	49.4	0.003280	0.106940	2.658	31.743
47.8- 41.9	44.2	0.006921	0.113861	6.265	38.007
41.9- 36.8	38.6	0.006645	0.120506	6.880	44.887
36.8- 29.3	31.8	0.014672	0.135178	18.463	63.351
29.3- 23.4	25.2	0.015822	0.151000	25.140	88.491
23.4- 20.3	21.2	0.009893	0.160893	18.694	107.185
20.3- 18.4	19.0	0.007847	0.168740	16.533	123.718
18.4- 17.3	17.6	0.005275	0.174014	11.969	135.687
17.3- 16.3	16.7	0.006028	0.180042	14.459	150.146
16.3- 15.4	15.7	0.007389	0.187431	18.816	168.962
15.4- 14.4	14.7	0.009062	0.196493	24.627	193.589
14.4- 13.3	13.7	0.011598	0.208090	33.857	227.445
13.3- 12.2	12.8	0.015537	0.223628	49.242	276.688
12.2- 11.2	11.5	0.018398	0.242023	63.912	340.600
11.2- 10.1	10.4	0.020849	0.262873	79.811	420.410
10.1- 8.8	9.2	0.036783	0.299656	169.095	589.505
8.8- 6.2	6.8	0.089513	0.389169	529.803	1110.308
6.2- 4.0	4.3	0.077911	0.467080	719.521	1829.829

LIQUID EQUIVALENT OF MAXIMUM VOLUME SORBED: 0.595708 CC/G

SORPTOMATIC 1990 , EDMONTON NITROGEN
STATION 2 STARTED 12/ 2/91 16:18 COMPLETED 12/ 3/91 6:55

INCREMENTAL PORE VOLUME DISTRIBUTION (ADSORPTION)

% OF MAXIMUM PORE VOLUME VERSUS AVERAGE PORE DIAMETER, ANGSTROMS
MAX INC PORE VOLUME = 0.089513 CC/G MAX INC FOR PLOT = 0.089513 CC/G

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              20%          40%          60%          80%         100%
   I'''''''''''''I''''''''''''I''''''''''''I''''''''''''I''''''''''''I
 3.5 ************************************************************
 4.4 ************************************************************
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10.6 ****************
13.2 **********
16.5 *****
20.5 *******
25.6 ************
31.9 ************
39.7 *****
49.5 **
61.6 *****
76.8 ***
95.7 ********
119.2 ******************
148.5 ******************
185.0 ******************
230.5 ******************
287.1 ******************
357.7 ************************
445.6
555.2
691.7
861.7
1073.5
1337.4
1666.1
2075.7
2585.9
3221.5
4013.4
5000.0
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[redacted]TRASORB300 , EDMONTON NITROGEN
[redacted]TION 2 STARTED 12/ 2/91 16:18 COMPLETED 12/ 3/91 6:55

INCREMENTAL PORE AREA DISTRIBUTION (ADSORPTION)

% OF MAXIMUM PORE AREA VERSUS AVERAGE PORE DIAMETER, ANGSTROMS
MAX INC PORE AREA = 719.521 SQ M/G MAX INC FOR PLOT = 719.521 SQ M/G

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                20%          40%          60%          80%          100%
    I.....I.....I.....I.....I.....I.....I.....I.....I.....I
  3.5 **************************************************************
  4.4 **************************************************************
  5.5 ************************************************************
  6.8 ********************************************
 [redacted]8.5 ************************
 [redacted]0.6 *******
 13.2 ****
 [redacted]8.5 *
 [redacted]0.5 **
 25.6 **
 31.9 **
 [redacted]9.7 *
 [redacted]9.5
 61.6
 [redacted]6.8
 [redacted]5.7
119.2 *
[redacted]48.5 *
[redacted]5.0
[redacted]0.5
287.1
[redacted]7.7
[redacted]5.6
555.2
[redacted]1.7
[redacted]1.7
[redacted]73.5
[redacted]37.4
[redacted]6.1
[redacted]5.7
1585.9
[redacted]1.5
[redacted]0.4
2000.0
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1019 m²/g
0.6 cc/g

SAMPLE 22 , COCONUT CARBON NITROGEN
STARTED 12/ 7/91 16:18

PRESSURE (MMHG)	VOL ADSORBED (CC STP/G)	ELAPSED TIME (HR:MN)	SATURATION PRESS (MMHG)	BET SURFACE AREA ESTIMATE (M2/G)
		0: 0	727.213	
0.005	45.7218	0: 9		
0.013	95.0294	0:27		
0.045	143.8867	0:41		
		0:43	727.215	
0.242	192.7973	1: 3		
3.380	241.0428	1:23		
		1:25	726.709	
31.931	287.8256	1:59		
		2: 2	726.340	
36.030	290.3516	2:12		
51.882	297.4906	2:26		
68.676	302.2638	2:37		
		2:39	726.937	
83.068	304.9965	2:48		
99.625	307.4461	2:57		
114.522	309.2551	3: 6		
128.874	310.6337	3:14		
		3:17	726.291	
142.040	311.7170	3:25		
155.356	312.6120	3:31		1049.732
181.527	314.2436	3:40		
219.148	316.0663	3:47		
		3:50	726.119	
290.227	318.5049	3:56		
361.277	320.2664	4: 1		
397.903	321.0861	4: 6		
434.754	321.8796	4:10		
453.120	322.3385	4:15		
471.602	322.8691	4:19		
508.003	323.3667	4:23		
		4:26	725.187	
524.368	324.0153	4:31		
545.042	324.2439	4:35		
577.842	324.8776	4:39		
651.134	326.8412	4:48		
690.045	327.6948	4:53		
		4:55	724.859	
701.303	328.1604	5: 0		
		5: 2	723.302	

ARC - COAL AND HYDROCARBON PROCESSING DEPT.(SURFACE LABORATORY)

DIGISORB 2600 V3.03

...SE / COCONUT CARBON NITROGEN

...ATION 1 STARTED 12/ 2/91 16:18 COMPLETED 12/ 3/91 0:11

ISOTHERM PLOT

% OF MAXIMUM VOLUME VERSUS RELATIVE PRESSURE

AX VOL SORBED = 329.4604 CC/G STP MAX VOL FOR PLOT = 329.4604 CC/G STP

NU-22 , COCONUT CARBON NITROGEN
TATION 1 STARTED 12/ 2/91 16:18 COMPLETED 12/ 3/91 0:11

ADSORPTION ISOTHERM

PLE WEIGHT: 0.3083 G EQUILIBRATION INTERVAL: 10 SECS
LE SPACE: 89.0890 CC MAX VOL INCREMENT: 50.000 CC/G STP

P/PO	VOL ADSORBED (CC/G AT STP)
0.000007	45.722
0.000018	95.029
0.000062	143.69
0.000333	192.80
0.004665	241.04
0.04396	287.83
0.04959	290.35
0.07139	297.49
0.09448	302.26
0.1143	305.00
0.1371	307.45
0.1576	309.26
0.1774	310.63
0.1956	311.72
0.2139	312.61
0.2500	314.24
0.3018	316.07
0.3998	318.50
0.4978	320.27
0.5483	321.09
0.5992	321.88
0.6246	322.34
0.6502	322.87
0.7005	323.37
0.7231	324.02
0.7517	324.24
0.7870	324.68
0.8982	326.84
0.9519	327.69
0.9947	329.46

NO. 22 , COCONUT CARBON NITROGEN
ATION 1 STARTED 12/ 2/91 18:18 COMPLETED 12/ [illegible] 0:11

SPECIFIC SURFACE AREA

BET SURFACE AREA:	1049.7423	+/-	18.5443 SQ M/G
SLOPE:	0.004198	+/-	0.000073
INTERCEPT:	-0.000051	+/-	0.000010
C:	-81.5044		
VM:	241.1427 CC		
CORRELATION COEFFICIENT	0.9998		

LANGMUIR SURFACE AREA:	1395.6738	+/-	1.6866 SQ M/G
SLOPE:	0.003119	+/-	0.000004
INTERCEPT:	0.000016	+/-	0.000001
A*PO:	174.7093		
VM:	320.8098 CC		
CORRELATION COEFFICIENT	1.0000		

RELATIVE PRESSURE RANGE: 0.0500 TO 0.2100

RC-22 , COCONUT CARBON NITROGEN
TATION 1 STARTED 12/ 2/91 16:18 COMPLETED 12/ 3/91 0:11

ADSORPTION PORE VOLUME AND PORE AREA DISTRIBUTIONS

PORE DIA. RANGE, A	AVERAGE DIA.,A	PORE VOLUME (CC/G)	CUMULATIVE PORE VOLUME	PORE AREA (SQ M/G)	CUMULATIVE PORE AREA
648.4- 414.9	451.5	0.002642	0.002642	0.234	0.234
414.9- 205.5	241.9	0.001498	0.004140	0.248	0.482
205.5- 104.4	121.5	0.004276	0.008416	1.407	1.889
104.4- 81.6	88.3	0.000771	0.009187	0.349	2.238
81.6- 72.2	75.6	0.000403	0.009589	0.213	2.451
72.2- 66.1	68.5	0.001402	0.010991	0.818	3.269
66.1- 58.3	60.1	0.000943	0.011934	0.627	3.897
58.3- 51.5	53.2	0.001162	0.013096	0.873	4.770
51.5- 47.8	49.3	0.000991	0.014087	0.805	5.575
47.8- 41.8	44.1	0.001700	0.015787	1.541	7.116
41.8- 36.6	38.5	0.001787	0.017575	1.856	8.972
36.6- 29.4	31.8	0.004013	0.021587	5.046	14.018
29.4- 23.3	25.1	0.005898	0.027485	9.380	23.398
23.3- 20.1	21.0	0.004542	0.032027	8.633	32.031
20.1- 18.2	18.8	0.004142	0.036169	8.807	40.838
18.2- 17.1	17.5	0.002220	0.038389	5.087	45.925
17.1- 16.3	16.6	0.002775	0.041164	6.689	52.614
16.3- 15.4	15.7	0.003572	0.044736	9.097	61.711
15.4- 14.4	14.8	0.004806	0.049542	13.016	74.726
14.4- 13.4	13.8	0.006527	0.056070	18.974	93.701
13.4- 12.4	12.7	0.007314	0.063383	22.978	116.679
12.4- 11.3	11.7	0.013230	0.076614	45.344	162.023
11.3- 10.1	10.5	0.019952	0.096566	76.283	238.305
10.1- 9.5	9.6	0.006841	0.103407	28.551	266.857
9.5- 6.8	7.5	0.120310	0.223717	645.715	912.571
6.8- 4.3	4.6	0.082205	0.305922	709.681	1622.253

LIQUID EQUIVALENT OF MAXIMUM VOLUME SORBED: 0.509609 CC/G

NC-22 , COCONUT CARBON NITROGEN
STATION 1 STARTED 12/ 2/91 16:18 COMPLETED 12/ 3/91 0:11

INCREMENTAL PORE VOLUME DISTRIBUTION (ADSORPTION)

% OF MAXIMUM PORE VOLUME VERSUS AVERAGE PORE DIAMETER, ANGSTROMS
MAX INC PORE VOLUME = 0.120310 CC/G MAX INC FOR PLOT = 0.120310 CC/G

```
          20%          40%          60%          80%         100%
     I............I............I............I............I............I
  3.5 **************************************************
  4.4 **************************************************
  5.5 ************************************************************
  6.8 ************************************************************************
  8.5 ********************************
 10.6 **********
 13.2 ****
 16.5 **
 20.5 **
 25.6 ***
 31.9 **
 39.7 *
 49.5 *
 61.6 *
 76.8
 95.7 *
119.2 **
148.5 **
185.0 *
230.5 *
287.1 *
357.7 *
445.6 *
555.2
691.7
861.7
1073.5
1337.4
1666.1
2075.7
2585.9
3221.3
4012.4
5000.0
```

NC-22 , COCONUT CARBON NITROGEN
STATION 1 STARTED 12/ 2/91 16:13 COMPLETED 12/ 3/91 0:11

INCREMENTAL PORE AREA DISTRIBUTION (ADSORPTION)

% OF MAXIMUM PORE AREA VERSUS AVERAGE PORE DIAMETER, ANGSTROMS
MAX INC PORE AREA = 709.681 SQ M/G MAX INC FOR PLOT = 709.681 SQ M/G

```
              20%          40%          60%          80%         100%
    I.....I.....I.....I.....I.....I.....I.....I.....I.....I.....I
  3.5 **************************************************************
  4.4 **************************************************************
  5.5 ************************************************************
  6.8 ***********************************************************
  8.5 *******************************
 10.6 *******
 13.2 **
 16.5 *
 20.5 *
 25.6 *
 31.9
 39.7
 49.5
 61.6
 76.8
 95.7
119.2
148.5
185.0
230.5
287.1
357.7
445.6
555.2
691.7
861.7
1073.5
1337.4
1666.1
2075.7
2585.8
3221.5
4012.4
5000.0
```

104 m²/g
0.51 cc/g

APPENDIX III

Evaluation of Activated Carbon Produced by the Coal and Hydrocarbon Processing Department of Alberta Research Council

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January, 1992

1. Introduction

To evaluate activated carbon samples produced by the Coal and Hydrocarbon Processing Department of Alberta Research Council (ARC), a number of physical and chemical tests were performed. In total four activated carbons produced by ARC were tested. As well appropriate commercially available activated carbons were selected and tested to allow direct comparison. The Brunauer, Emmet and Teller Method (BET Method) surface area of each carbon was determine by ARC. Standard tests used in the evaluation of activated carbon for water and wastewater treatment applications were performed at the Environmental Engineering and Science Laboratory at the University of Alberta. These tests included the iodine number, methylene blue number, modified phenol value, mesitylene value and tannin value. In addition gold adsorption rate tests and gold adsorption capacity tests were performed on each carbon to determine its applicability in gold recovery.

This report presents the results of the tests as well as a brief description of each test and its significance. A discussion of the results is also presented.

2. Description and Significance of Tests

2.1 Surface Area

The surface area is the amount of surface area per unit weight of carbon. It is determined from the nitrogen adsorption isotherm by the Brunauer, Emmet and Teller Method (BET Method). It is usually expressed as square meters per gram of carbon.

Adsorption is a surface phenomenon, so surface area is a general criteria for the capability of a particular carbon for adsorption. However, the BET surface area does not tell anything about surface chemistry of the carbon and pore size distributions are required to indicate the surface accessible to large molecules.

2.2 Iodine Number

The iodine number is the milligrams of iodine absorbed by one gram of carbon at an equilibrium filtrate concentration of 0.02N iodine. The iodine test is an index of the total surface area of a carbon and may be used to show whether a carbon is activated. The test is also an index for the adsorption capacity of the carbon for low weight compounds.

A minimum value for the iodine number of 500 mg/g is suggested by the American Water Works Association (AWWA 1978), to select a powdered activated carbon (PAC) for the removal of typical low molecular weight, taste and odour causing organic compounds.

2.3 Methylene Blue Number

The methylene blue number is the milligrams of methylene blue ($C_{16}H_{18}N_3SCl$) adsorbed by one gram of carbon in equilibrium with a solution of methylene blue having a concentration of 1.0 mg/L. This test is an index for the ability of carbon to adsorb large molecules.

2.4 Modified Phenol Value

The modified phenol value is defined as the dosage of carbon required to remove 90% of a 200 mg/L phenol solution. It is normally expressed in g/L. A low modified phenol value indicates a high adsorption capacity for phenol. The AWWA suggests a maximum value of 3.5 g/L for this index.

The modified phenol value is an index for the adsorptive capacity of the carbon for polar, ionic and low molecular weight organic compounds.

2.5 Mesitylene Value

The mesitylene value is not a standard test used in activated carbon, however it has been used by Troxler et al. (1988), as a supplement to the modified phenol value test in assessing adsorption capacity for low molecular weight compounds. Mesitylene (1,2,5-trimethylbenzene) is a non-polar, aromatic hydrocarbon with an odour threshold concentration of 3 µg/L (Zoeteman et al. 1980). It is found in surface waters and has been linked to taste and odour problems in drinking water.

This isotherm test measures the amount of mesitylene adsorbed after six days of mixing, at 5 °C. The test is done at 5 °C to simulate conditions often found in drinking water treatment in Edmonton. Similar to the modified phenol value, it is defined as the dosage of carbon that removes 90% of a 10 mg/L solution of mesitylene. As a result, a low mesitylene value indicates a high adsorption capacity for mesitylene.

One difficulty with this test is that mesitylene is very volatile and significant losses can occur during the test, resulting in higher variance in the results.

2.6 Tannin Value

The tannin value test measures the adsorption capacity for tannic acid (or gallotannic acid, $C_{76}H_{58}O_{46}$). The tannin value is the dosage of carbon required to adsorb 90% of a 20 mg/L tannic acid solution. A value of 270 mg/L or lower is suggested for effective removal of high molecular weight organics (Troxler et al. 1988).

The tannin value is used as an indicator of the potential for the adsorption of aquatic humic substances and of colour-imparting organic compounds. These compounds tend to be large and complex, and carbons with good tannin values, possess large pores.

2.7 Evaluation for Gold Recovery

For the evaluation of activated carbon for gold recovery the following factors are normally used (Faulkner et al 1987):

1. Adsorption rate;
2. Adsorption capacity;
3. Iodine number and carbon tetrachloride number;
4. Particle size;
5. Attrition characteristics; and
6. Desorption characteristics.

Adsorption rate and adsorption capacity have been found to be the most important characteristics. Adsorption rate is generally accepted as the more fundamentally important adsorption criteria by factors 3:1 to 5:1 over equilibrium adsorption capacity for gold. Iodine and carbon tetrachloride determinations were not found to be adequate criteria for prediction of carbon performance in gold recovery applications (Faulkner et al. 1987).

3.0 Test Results

For the standard tests used in assessing carbon in water and wastewater applications, the commercially available carbon chosen for comparison purposes, was Filtrasorb 300. Filtrasorb 300 is produced by Calgon Carbon Corporation from bituminous coal. It is widely used in water and wastewater applications for the removal of taste, odours and synthetic organic contaminants. Filtrasorb 300 is activated to produce a high internal surface area with optimum pore size for effective adsorption of a broad range of high and low molecular weight organic contaminants (Calgon, 1990).

For the gold recovery tests the carbon selected for comparison was GRC-22. This carbon is also produced by Calgon Carbon Corporation specifically for gold recovery applications. It is a coconut-based carbon product, which meets the rigid hardness specifications required in gold recovery applications.

3.1 Experimental Methods

All carbon samples were dried overnight at 150 °C prior to evaluation. All tests except gold adsorption rate were performed using 325 mesh carbon samples. The gold adsorption rate was determined using 30 to 50 mesh carbon.

Procedures used to determine iodine number, modified phenol value and tannin value are described in the AWWA B600-78 Standard for Powdered Activated Carbon. The determination of mesitylene value was performed as described by Troxler et al. (1988). The gold adsorptive capacity (K- value) and gold adsorption rate was determined as outlined in Faulkner et al. (1987). However, for the adsorption rate test 30 to 50 mesh carbon was used with an initial gold concentration of 20 mg/L.

The methylene blue number was determined using the following procedure. An accurately weighed 100.0 mg carbon subsample was mixed with a 25.0 mL aliquot of 1.20 g/L methylene blue in 5% acetic acid. After mixing for 30 minutes, the suspension was filtered through Whatmen #44 filter paper. The first 5 mL of filtrate was discarded. The filtrate was diluted 1:100 with 0.25 % acetic acid and absorbance at 620 nm was measured. The methylene blue value was obtained from a calibration curve relating absorbance to grams methylene blue adsorbed per gram of carbon (as described in EPA 625/1-71-002a).

3.2 Results From Tests Used in Water and Wastewater Applications

Table 1 summarizes the results from the tests. The data and isotherms are presented in Appendix I. Carbons received from ARC ranged in BET surface area from 772 to 1239 m^2/g. This compares to 1018 m^2/g for the Filtrasorb 300 and 1050 m^2/g for the GRC-22. As expected trends in the iodine numbers follow closely those seen in the BET surface area, as the iodine number is an index for surface area. However, it was found that even though the MTK-1016 carbon has a BET surface area that is over 200 m^2/g greater than the Filtrasorb 300 the iodine number for the Filtrasorb 300 was approximately equivalent to the MTK-1016. All carbons tested had a Iodine number greater than 500 mg/g which is the minimum value suggested by the AWWA.

Table 1. Summary of Results

Carbon Sample	Surface area (m2/g)	Iodine number (mg/g)	Methylene blue number (g/100g carbon)	Modified Phenol value (g/L)	Mesitylene value (mg/L)	Tannin value (mg/L)	Gold Adsorption Rate (R value)	Gold Adsorption Capacity (K value) (mg/g)
MTK-0813	772	744 (705, 783)	16.76 (16.20, 17.32)	3.98 (3.95, 4.00)	50.6 (42.5, 60.2)	1032 (765, 1392)	5.94 (5.93, 5.96)	18.8 (18.7, 19.0)
MTK-0822	871	783 (749, 817)	17.71 (17.62, 17.80)	3.91 (3.87, 3.94)	37.0 (32.9, 41.6)	1375 (1021, 1858)	5.28 (5.26, 5.29)	20.6 (20.3, 21.0)
MTK-1016	1239	1051 (1004, 1098)	24.68 (23.56, 25.80)	2.67 (2.64, 2.69)	21.6 (16.3, 28.6)	1525 (1467, 1579)	14.65 (14.61, 14.70)	28.8 (28.5, 29.0)
MTK-1023	870	802 (793, 811)	17.54 (16.94, 18.14)	3.34 (3.30, 3.38)	27.8 (25.7, 30.2)	1376 (1266, 1495)	6.27 (6.25, 6.29)	24.2 (23.9, 24.5)
Filtrasorb 300	1018	1087 (1044, 1130)	24.56 (24.13, 24.99)	1.73 (1.49, 2.01)	11.0 (10.7, 11.3)	273 (271, 276)	-	-
Calgon GRC-22	1050	-	-	-	-	-	3.95 (3.94, 3.96)	36.6 (36.0, 37.3)

* values in parenthesis indicate 95% confidence limits

For the methylene blue tests the MTK-1016 carbon again performed similarly to the Filtrasorb. The methylene blue test is a measure of the decolourizing ability of the carbon. Methylene blue is a relatively large molecule ($C_{16}H_{18}N_3SCl$) and hence is also used to determine the capacity of activated carbons for larger molecules. Results from the methylene blue tests follow the same trends as the surface area and iodine numbers; carbons with higher surface areas and iodine numbers having higher methylene blue numbers.

For the next three tests, modified phenol number, mesitylene value and tannin value, the ARC carbons did not performed as well as Filtrasorb 300. As mentioned, these values are based on the carbon dose required to remove 90% of the given chemical. Therefore, a low value is an indication of high adsorption capacity for that chemical. For the modified phenol test, only two ARC carbons (MTK-1016 and MTK-1023) had a value below the AWWA suggested maximum of 3.5 g/L. However, the value for MTK-1016 was still substantially higher than Filtrasorb 300. As mentioned earlier, the modified phenol value is an index for the adsorptive capacity of the carbon for polar and low molecular weight organic compounds.

The mesitylene value can be used as a supplement to the modified phenol value. Similar to the modified phenol tests, the ARC carbons did not perform well compared to the Filtrasorb 300. The tannin number is an indicator for the adsorption capacity of the carbon for large humic substances and colour-imparting organic compounds. The values for the ARC carbons were close to four times that of the Filtrasorb 300.

The ARC carbons performed well in the iodine number tests and the methylene blue tests. However, they did not perform well in the tests that involve polar and aromatic compounds, and organic acids. As will be discussed later, this may be related to surface chemistry of the carbon.

3.3 Results From Gold Recovery Tests

The most important factor in assessing the applicability of a carbon for gold recovery is the adsorption rate of gold. The rate of adsorption is heavily dependent on particle size. In the standard test a mean particle diameter of 2.19 mm is used. However, none of the carbon produced by ARC was of this size. The largest size produced was 30 to 50 mesh. All rate tests, including the Calgon GRC-22 were done with carbon of this size. This allows

comparison of the carbons tested, however, the rate values presented should not be compared to other published values which are done with the larger standard carbon size. The smaller particle size results in higher rate constants.

From Table 1 it is evident that all of the ARC carbons performed well in the gold adsorption rate tests, with all of them out performing the Calgon GRC-22 carbon. The MTK-1016 performed especially well in the tests. In the capacity tests the GRC-22 was better than the ARC carbons, with the MTK-1016 being the second best. However, as mentioned, adsorption rate is more important than capacity in selecting a carbon.

4.0 Discussion and Conclusions

The results indicate that Alberta Research Council has produced carbons with surface area and pore size distribution characteristics that should be applicable for water and wastewater applications. This is evident by the performance of the carbons in the iodine and methylene blue tests. In these tests carbon MTK-1016 performed as well as Calgon's Filtrasorb 300, a carbon widely used in water and wastewater applications. The relatively poor performance of the ARC carbons in the modified phenol, mesitylene and tannin tests is probably related to surface chemistry effects rather than surface area or pore size distribution. This could be improved through modification of the activation process used.

Phenol is a polar aromatic compound, mesitylene is a nonpolar aromatic compound and tannic acid is a large organic acid. Giusti et al. (1974) showed that an increase in surface oxides reduces the ultimate adsorption capacity of activated carbon for alcohols, ketones, aldehydes, esters and organic acids. Acidic surface oxides, such as carboxyl-type functional groups, have been found to hinder the adsorption of anionic adsorbates, aromatics such as phenol and related nitrophenols, non-polar aliphatics such as decane and humic substances (Coughlin and Ezra, 1968; Cookson, 1975; McCreary and Snoeyink, 1980). Altering the activation procedure such that there are fewer acidic surface oxides could improve results in the modified phenol, mesitylene and tannin tests.

The results indicate that carbons produced by ARC have adsorption characteristics amenable to gold recovery applications. However, as mentioned, the primary reason the coconut based carbons are used in gold recovery is their hardness characteristics and low

attrition rates, rather than their adsorption characteristic. The greatest problem with the use of coal based carbons in gold recovery is that they have higher attrition rates.

5.0 References

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Appendix I

Data and Isotherms

Table A.1. Data from modified phenol tests.

Carbon Sample	Carbon Dose (g)	Phenol residual (mg/L)	Carbon Loading (%/ g/L)
MTK-0813	0.1579	92.39	28.67
	0.2078	71.98	27.60
	0.3286	32.42	24.59
	0.3685	22.00	23.60
MTK-0822	0.1615	84.95	30.76
	0.2157	63.96	28.80
	0.2555	47.85	28.04
	0.3072	33.62	26.07
	0.3500	24.26	24.47
MTK-1016	0.1655	51.52	41.98
	0.2490	19.92	35.42
	0.3012	10.73	31.09
	0.3564	6.22	27.02
MTK-1023	0.1662	74.47	33.63
	0.2056	55.17	32.74
	0.2526	38.38	30.59
	0.3017	22.93	28.64
	0.3624	12.75	25.51
Filtrsorb 300	0.1614	20.51	54.43
	0.2046	7.55	46.69
	0.2621	0.41	38.07
	0.3248	0.00	30.79
	0.3727	0.00	26.83

Table A.2. Data from mesitylene tests

Carbon Sample	Carbon Dose (mg)	Mesitylene residual (%)	Carbon Loading (%/ mg/L)	GC area
MTK-0813	6.6	64.50	5.38	25465
	10.2	56.69	4.25	22413
	19.3	32.71	3.49	13050
MTK-0822	7.3	37.99	8.50	15111
	9.9	31.14	6.96	12438
	21.5	18.55	3.79	7521
	27.6	12.35	3.18	5100
MTK-1016	5.3	52.49	8.96	20775
	10.2	36.98	6.18	14720
	19.9	11.09	4.47	4611
MTK-1023	5.5	76.45	4.28	30129
	25.7	11.88	3.43	4918
	32.1	5.96	2.93	2608
Filtrasorb 300	7.5	25.48	9.94	10228
	9.5	13.29	9.13	5469
	13.8	5.28	6.86	2342

Table A.3. Data from tannin tests.

Carbon Sample	Carbon Dose (mg)	Tannic Acid Residual (mg/L)	Carbon Loading (mg/mg)
MTK-0813	2007.6	0.54	0.0078
	1255.0	0.84	0.0122
	501.8	4.14	0.0253
MTK-0822	2003.3	1.06	0.0076
	1250.2	1.45	0.0119
	507.2	4.91	0.0238
MTK-1016	2016.6	0.82	0.0076
	1250.4	1.98	0.0115
	509.4	6.36	0.0214
MTK-1023	2003.4	0.74	0.0077
	1250.0	1.51	0.0118
	503.7	5.92	0.0224
Filtrasorb 300	323.4	0.66	0.0478
	242.8	1.49	0.0610
	177.5	3.38	0.0749
	83.0	9.22	0.1039
	44.4	13.58	0.1156

Table A.4. Gold adsorption rate data

Carbon Sample	Time (minutes)	Gold residual conc. (mg/L)	Carbon Loading (mg Au/g carbon)	time/loading
MTK-0813	0	19.76	0.00	
	15	8.02	19.96	0.75
	30	3.91	26.95	1.11
	60	2.82	28.80	2.08
	120	2.17	29.90	4.01
	480	1.82	30.50	15.74
MTK-0822	0	20.26	0.00	
	15	8.74	19.58	0.77
	30	4.07	27.52	1.09
	60	2.18	30.74	1.95
	120	1.35	32.15	3.73
	480	1.11	32.56	14.74
MTK-1016	0	18.28	0.00	
	15	4.00	24.28	0.62
	30	1.49	28.54	1.05
	60	0.80	29.71	2.02
	120	0.66	29.95	4.01
	480	0.57	30.11	15.94
MTK-1023	0	19.68	0.00	
	15	7.53	20.66	0.73
	30	3.42	27.64	1.09
	60	1.18	31.45	1.91
	120	0.80	32.10	3.74
	480	0.62	32.40	14.81
Calgon GRC-22	0	18.23	0.00	
	15	8.19	17.07	0.88
	30	4.24	23.78	1.26
	60	1.68	28.14	2.13
	120	0.78	29.66	4.05
	480	0.53	30.10	15.95

Table A.5. Gold capacity test data.

Carbon Sample	Carbon Dose (mg)	Gold residual conc. Co=110.45 (mg/L)	Normalized residual to Co=100 (mg/L)	Carbon Loading (mg Au/g carbon)
MTK-0813	114.9	47.62	43.11	49.51
	202.1	20.96	18.98	40.09
	307.8	7.40	6.70	30.31
	414.1	2.76	2.50	23.55
	503.4	1.28	1.16	19.63
	611.1	0.62	0.56	16.27
MTK-0822	106.4	46.30	41.92	54.59
	215.7	16.74	15.16	39.33
	306.6	5.33	4.83	31.04
	420.3	1.60	1.45	23.45
	526.7	0.72	0.65	18.86
	610.4	0.51	0.46	16.31
MTK-1016	120.8	27.35	24.76	62.28
	206.3	7.22	6.54	45.30
	314.7	1.60	1.45	31.32
	406.5	0.61	0.55	24.46
	506.8	0.24	0.22	19.69
	636.8	0.08	0.07	15.69
MTK-1023	117.4	40.91	37.04	53.63
	206	13.33	12.07	42.69
	318	3.08	2.79	30.57
	404.9	1.13	1.02	24.44
	504.1	0.46	0.42	19.75
	631.7	0.16	0.15	15.81
Calgon GRC-22	107.8	20.38	18.45	75.65
	209.2	2.34	2.12	46.79
	313.2	0.71	0.65	31.72
	424.3	0.17	0.16	23.53
	515.2	0.09	0.08	19.39
	612.4	0.05	0.05	16.32

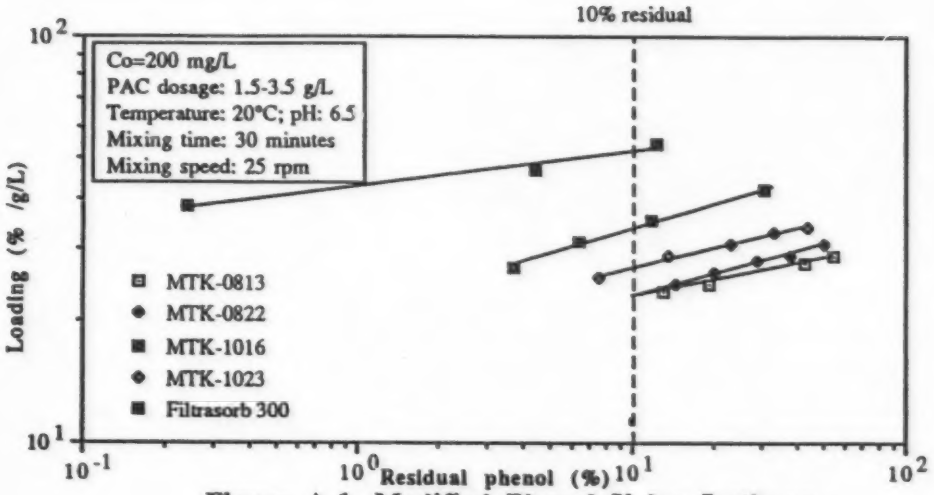

Figure A-1. Modified Phenol Value Isotherm

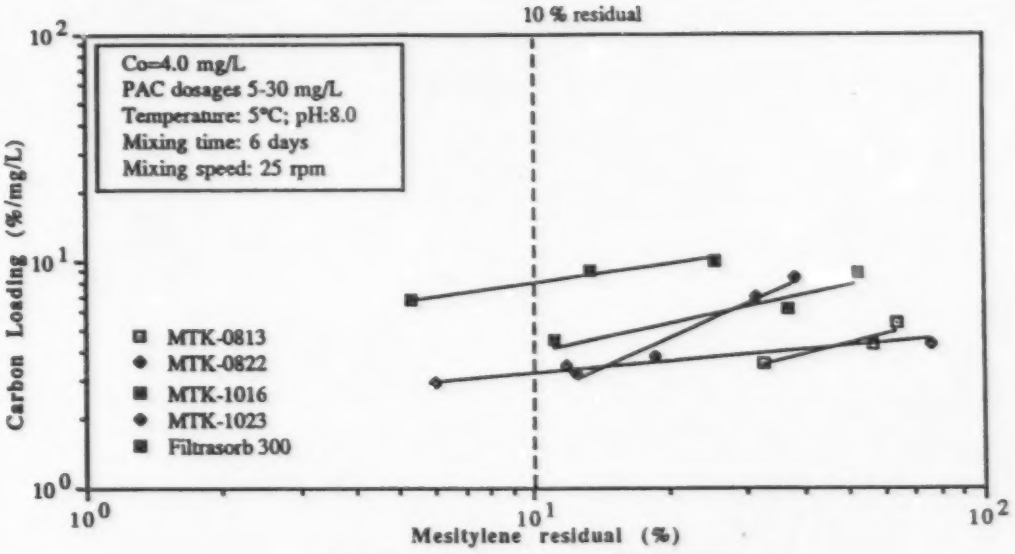

Figure A-2. Mesitylene Isotherms

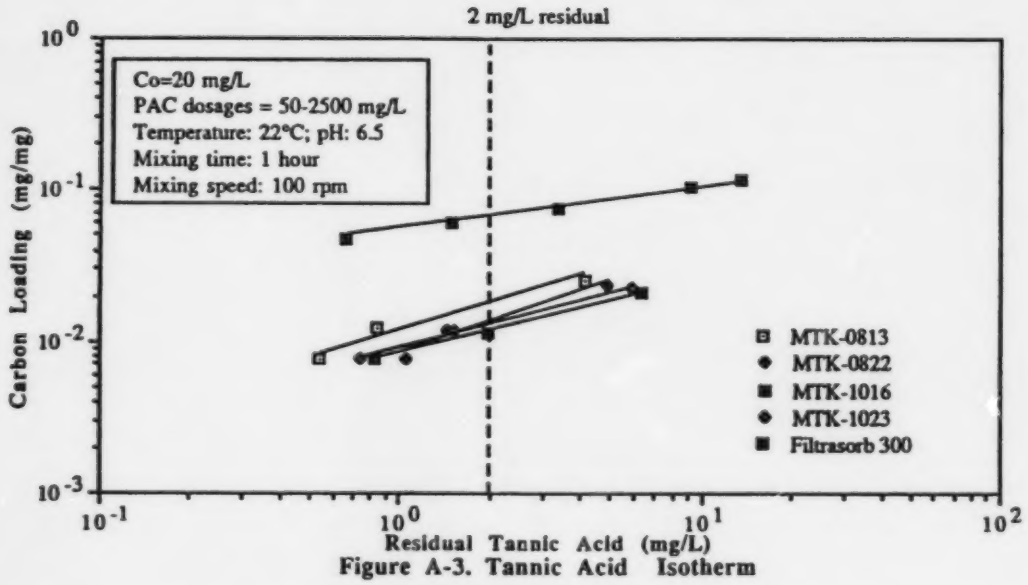

Figure A-3. Tannic Acid Isotherm

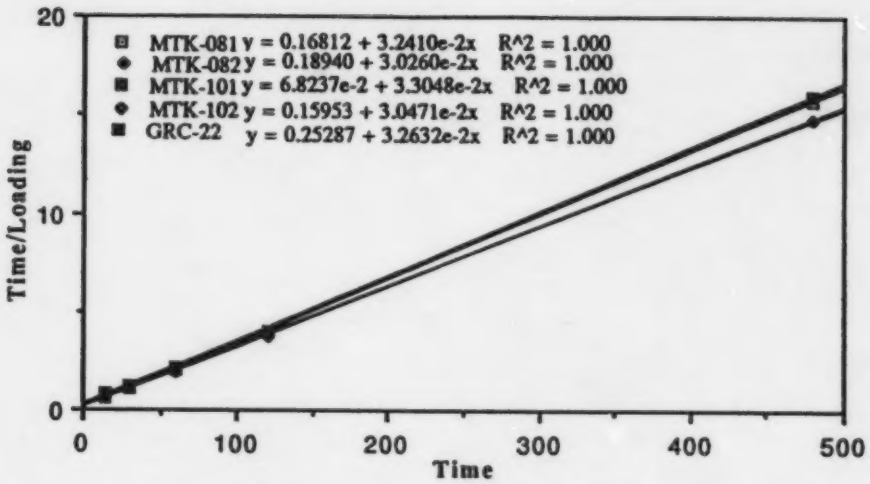

Figure A-4. Gold Rate Tests

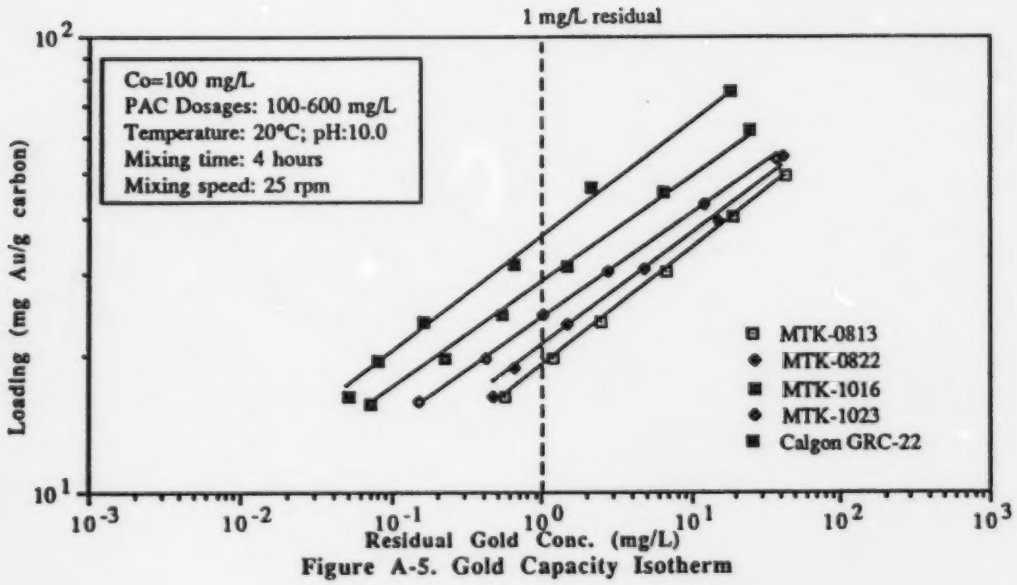

Figure A-5. Gold Capacity Isotherm

APPENDIX IV

Constant Dollar Preliminary Economic Analysis of the Manufacture and Sale of Activated Carbon

1.0 Negative Cash Flows — all cash flows in millions of dollars

		Year	0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20
1.1 Capital Investments			356	$.00	$.00	$.00	$.00	$.15	$.00	$.00	$.00	$.00	$.20	$.00	$.00	$.00	$.00	$.25	$.00	$.15	$.00	$.15	$.00
1.2 Plant Operating Costs				$21.36	$21.36	$21.36	$21.36	$21.36	$21.36	$21.36	$21.36	$21.36	$21.36	$21.36	$21.36	$21.36	$21.36	$21.36	$21.36	$21.36	$21.36	$21.36	$21.36
1.3 Feedstock Costs				$41.50	$41.50	$41.50	$41.50	$41.50	$41.50	$41.50	$41.50	$41.50	$41.50	$41.50	$41.50	$41.50	$41.50	$41.50	$41.50	$41.50	$41.50	$41.50	$41.50
1.4 Capital for Depreciation	36			$356.00	$231.40	$150.41	$97.77	$63.70	$41.40	$26.91	$17.49	$11.37	$7.59	$4.93	$3.21	$2.08	$1.36	$1.13	$.73	$.63	$.41	$.42	$.27
1.5 Annual Negative Cash Flows			356	$62.86	$62.86	$62.86	$62.86	$62.86	$62.86	$62.86	$62.86	$62.86	$62.86	$62.86	$62.86	$62.86	$62.86	$62.86	$62.86	$62.86	$62.86	$62.86	$62.86

2.0 Positive Cash Flows

			Yearly Total																				
2.1 Revenue	PAC	GAC	0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20
Projected Market for AC (tons/yr)	0	100800		100800	100800	100800	100800	100800	100800	100800	100800	100800	100800	100800	100800	100800	100800	100800	100800	100800	100800	100800	100800
Combined $ per ton (PAC and GAC)	$1500																						
Projected Capture of AC Market (tons/year)				100800	100800	100800	100800	100800	100800	100800	100800	100800	100800	100800	100800	100800	100800	100800	100800	100800	100800	100800	100800
Projected Revenues ($)				$190.20	$190.20	$190.20	$190.20	$190.20	$190.20	$190.20	$190.20	$190.20	$190.20	$190.20	$190.20	$190.20	$190.20	$190.20	$190.20	$190.20	$190.20	$190.20	$190.20
2.2 Depreciation Allowance ($)				$124.60	$80.99	$52.64	$34.22	$22.29	$14.49	$9.42	$6.12	$3.98	$2.66	$1.73	$1.12	$.73	$.47	$.40	$.26	$.22	$.14	$.15	$.09

3.0 Input Variables

3.1 Plant Capacity (tons/hr)	0.375
3.2 Capital Cost (million $)	$360.00
3.3 Coal Feedstock Cost ($/ton)	$35
3.4 Rate of Depreciation	35%
3.5 Captured % of Market	100%
3.6 Supplier Cost Factor	100%
3.7 Growth Factor	0.00%
3.8 PAC $ per ton	$0
3.9 GAC $ per ton	$1500
3.10 Activated Carbon Yield (%)	25%

4.0 Financial Indicators	Year 0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20
4.1 Before Tax Cash Flows		$127.34	$127.34	$127.34	$127.34	$127.34	$127.34	$127.34	$127.34	$127.34	$127.34	$127.34	$127.34	$127.34	$127.34	$127.34	$127.34	$127.34	$127.34	$127.34	$127.34
Depreciation Allowance		$124.60	$80.99	$52.64	$34.22	$22.29	$14.49	$9.42	$6.12	$3.98	$2.66	$1.73	$1.12	$.73	$.47	$.40	$.26	$.22	$.14	$.15	$.09
Net Loss Carry Forward		$.00	$.00	$.00	$.00	$.00	$.00	$.00	$.00	$.00	$.00	$.00	$.00	$.00	$.00	$.00	$.00	$.00	$.00	$.00	$.00
Net Taxable Income		$2.74	$46.35	$74.70	$93.12	$105.05	$112.85	$117.92	$121.22	$123.36	$124.68	$125.61	$126.22	$126.61	$126.87	$126.94	$127.08	$127.12	$127.20	$127.19	$127.25
4.2 Fed. and Prov. Taxes (50%)		$1.37	$23.18	$37.35	$46.56	$52.52	$56.42	$58.96	$60.61	$61.68	$62.34	$62.81	$63.11	$63.31	$63.43	$63.47	$63.54	$63.56	$63.60	$63.60	$63.62
4.3 After Tax Net Cash Flows	-356	$125.97	$104.17	$89.99	$80.78	$74.82	$70.92	$68.38	$66.73	$65.66	$65.00	$64.53	$64.23	$64.03	$63.91	$63.87	$63.80	$63.78	$63.74	$63.74	$63.89
4.4 Net Present Worth (NPW) @ 6%		$496.67																			
4.5 Internal Rate of Return (IRR)		25.0%																			
4.6 Modified IRR @ 7 % & 10 %		13.6%																			

Market of GAC @ $1500/ton, $ 0.035/Kw-hr electrical credit, and 360 million $ for Initial Capital Cost

Constant Dollar Preliminary Economic Analysis of the Manufacture and Sale of Activated Carbon

1.0 Negative Cash Flows		Year	0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20
				<---------- all cash flows in millions of dollars ----------																			>
1.1 Capital Investments			356	$.00	$.00	$.00	$.00	$.15	$.00	$.00	$.00	$.00	$.20	$.00	$.00	$.00	$.00	$.25	$.00	$.15	$.00	$.15	$.00
1.2 Plant Operating Costs				$21.36	$21.36	$21.36	$21.36	$21.36	$21.36	$21.36	$21.36	$21.36	$21.36	$21.36	$21.36	$21.36	$21.36	$21.36	$21.36	$21.36	$21.36	$21.36	$21.36
1.3 Feedstock Costs				$41.50	$41.50	$41.50	$41.50	$41.50	$41.50	$41.50	$41.50	$41.50	$41.50	$41.50	$41.50	$41.50	$41.50	$41.50	$41.50	$41.50	$41.50	$41.50	$41.50
1.4 Capital for Depreciation	36			$356.00	$231.40	$150.41	$97.77	$63.70	$41.40	$26.91	$17.49	$11.37	$7.59	$4.93	$3.21	$2.08	$1.36	$1.13	$.75	$.63	$.41	$.42	$.27
1.5 Annual Negative Cash Flows			356	$62.86	$62.86	$62.86	$62.86	$62.86	$62.86	$62.86	$62.86	$62.86	$62.86	$62.86	$62.86	$62.86	$62.86	$62.86	$62.86	$62.86	$62.86	$62.86	$62.86
2.0 Positive Cash Flows																							
		Yearly Total																					
2.1 Revenues	PAC	GAC	0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20
Projected Market for AC (tons/yr)	0	100800		100800	100800	100800	100800	100800	100800	100800	100800	100800	100800	100800	100800	100800	100800	100800	100800	100800	100800	100800	100800
Combined $ per ton (PAC and GAC)	$1000																						
Projected Capture of AC Market (tons/year)				100800	100800	100800	100800	100800	100800	100800	100800	100800	100800	100800	100800	100800	100800	100800	100800	100800	100800	100800	100800
Projected Revenues ($)				$139.80	$139.80	$139.80	$139.80	$139.80	$139.80	$139.80	$139.80	$139.80	$139.80	$139.80	$139.80	$139.80	$139.80	$139.80	$139.80	$139.80	$139.80	$139.80	$139.80
2.2 Depreciation Allowance ($)				$124.60	$80.99	$52.64	$34.22	$22.29	$14.49	$9.42	$6.12	$3.98	$2.66	$1.73	$1.12	$.73	$.47	$.40	$.26	$.22	$.14	$.15	$.09
3.0 Input Variables																							
3.1 Plant Capacity (tons/hr)	0.375																						
3.2 Capital Cost (million $)	$360.00																						
3.3 Coal Feedstock Cost ($/ton)	$35																						
3.4 Rate of Depreciation	35%																						
3.5 Captured % of Market	100%																						
3.6 Supplier Cost Factor	100%																						
3.7 Growth Factor	0.00%																						
3.8 PAC $ per ton	$0																						
3.9 GAC $ per ton	$1000																						
3.10 Activated Carbon Yield (%)	25%																						
			Year																				
4.0 Financial Indicators			0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20
4.1 Before Tax Cash Flows				$76.94	$76.94	$76.94	$76.94	$76.94	$76.94	$76.94	$76.94	$76.94	$76.94	$76.94	$76.94	$76.94	$76.94	$76.94	$76.94	$76.94	$76.94	$76.94	$76.94
Depreciation Allowance				$124.60	$80.99	$52.64	$34.22	$22.29	$14.49	$9.42	$6.12	$3.98	$2.66	$1.73	$1.12	$.73	$.47	$.40	$.26	$.22	$.14	$.15	$.09
Net Loss Carry Forward				$.00	-$47.66	-$51.71	-$27.41	$.00	$.00	$.00	$.00	$.00	$.00	$.00	$.00	$.00	$.00	$.00	$.00	$.00	$.00	$.00	$.00
Net Taxable Income				-$47.66	-$51.71	-$27.41	$15.31	$54.65	$62.45	$67.52	$70.82	$72.96	$74.28	$75.21	$75.82	$76.21	$76.47	$76.54	$76.68	$76.72	$76.80	$76.79	$76.85
4.2 Fed. and Prov. Taxes (50%)				$.00	$.00	$.00	$7.65	$27.32	$31.22	$33.76	$35.41	$36.48	$37.14	$37.61	$37.91	$38.11	$38.23	$38.27	$38.34	$38.36	$38.40	$38.40	$38.42
4.3 After Tax Net Cash Flows			-356	$76.94	$76.94	$76.94	$69.29	$49.62	$45.72	$43.18	$41.53	$40.46	$39.80	$39.33	$39.03	$38.83	$38.71	$38.67	$38.60	$38.58	$38.54	$38.54	$38.69
4.4 Net Present Worth (NPW) @ 6%				$220.94																			
4.5 Internal Rate of Return (IRR)				15.2%																			
4.6 Modified IRR @ 7 % & 10 %				11.4%																			

Market of GAC @ $1000/ton, $ 0.035/Kw-hr electrical credit, and 360 million $ for Initial Capital Cost